

WHAT LIES DEEP

in the Mantle Below?

A Weather Eye
on Coastal Winds

Gulf of Mexico Dead Zone

Understanding Low River
Flows as Climate Changes

AGU FALL MEETING

San Francisco | 14–18 December 2015

Save Money the Right Way



Act now to save on registration and housing.

**Housing and Early Registration Deadline:
12 November 11:59 P.M. EST**

To get the best rates, join or renew your
AGU membership by 14 October

fallmeeting.agu.org

15 SEPT 2015
VOLUME 96, ISSUE 17



10

COVER

What Lies Deep in the Mantle Below?

For decades, scientists have probed Earth's remote mantle by analyzing how seismic waves of distant earthquakes pass through it. But we are still challenged by the technique's limitations.

PROJECT UPDATE

16 A Weather Eye on Coastal Winds

New satellite radar image-processing system provides wind speed maps with an unprecedented degree of precision. Such maps will help coastal communities prepare for wind-related hazards.

NEWS

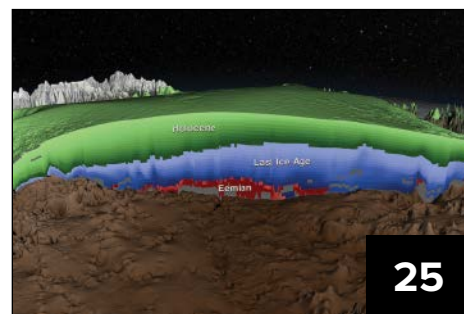


5

Guidelines Updated for Field Trip Guidebooks

A geoscience organization recently revised guidelines for preparing field trip guidebooks and updated its online searchable database for the guides.

RESEARCH SPOTLIGHT

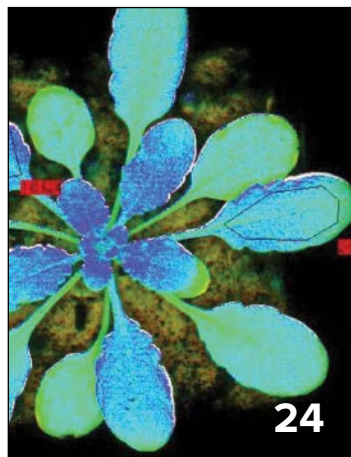


25

Ice-Penetrating Radar Reveals Age of Greenland Ice Sheet Layers

First comprehensive analysis of deep radar data gives insight into the dynamics and history of the Greenland Ice Sheet.

DEPARTMENTS



3–5 News

Gulf of Mexico Dead Zone Largest Since 2002; Geoscientists: Focus More on Societal Concerns; Guidelines Updated for Field Trip Guidebooks.

6 Meeting Report

Monitoring Gas Emissions Can Help Forecast Volcanic Eruptions.

7–9 Opinion

How Can We Better Understand Low River Flows as Climate Changes?

20–22 AGU News

Prioritizing Development; A Guide to Writing an AGU Abstract.

23–25 Research Spotlight

Lightning “Impulses” Improve Models of Global Electrical Circuit; Airborne Sensor Can Track Photosynthesis Efficiency; New Models Explain Unexpected Magnitude of China’s Wenchuan Quake; Ice-Penetrating Radar Reveals Age of Greenland Ice Sheet Layers.

27–32 Positions Available

Current job openings in the Earth and space sciences.

Inside Back Cover:
Postcards from the Field

Measuring carbon dioxide and methane on the Seward Peninsula in Alaska.

On the Cover

Approximately 2-meter skylight near the Pu’u Ō’ō vent on Hawaii’s Kilauea Volcano. Credit: © G. Brad Lewis/volcanoman.com.

EOS®

Editor in Chief

Barbara T. Richman: AGU, Washington, D. C., USA; eos_brichman@agu.org

Editors

Christina M. S. Cohen

California Institute of Technology, Pasadena, Calif., USA; cohen@srl.caltech.edu

Wendy S. Gordon

Ecologia Consulting, Austin, Texas, USA; wendy@ecologiaconsulting.com

Carol A. Stein

Department of Earth and Environmental Sciences, University of Illinois at Chicago, Chicago, Ill., USA; cstein@uic.edu

José D. Fuentes

Department of Meteorology, Pennsylvania State University, University Park, Pa., USA; juf15@meteo.psu.edu

David Halpern

Jet Propulsion Laboratory, Pasadena, Calif., USA; davidhalpern29@gmail.com

Editorial Advisory Board

M. Lee Allison, Earth and Space Science Informatics

Lora S. Armstrong, Volcanology, Geochemistry, and Petrology

Michael A. Ellis, Earth and Planetary Surface Processes

Arlene M. Fiore, Atmospheric Sciences

Nicola J. Fox, Space Physics

and Astronomy

Steve Frolking, Biogeosciences

Edward J. Garnero, Study of the Earth’s Deep Interior

Michael N. Gooseff, Hydrology

Kristine C. Harper, History of Geophysics

Keith D. Koper, Seismology

Robert E. Kopp, Geomagnetism and Paleomagnetism

John W. Lane, Near-Surface Geophysics

Xin-Zhong Liang, Global Environmental Change

Jian Lin, Tectonophysics

Figen Mekik, Paleoclimatology and Paleoclimatology

Jerry L. Miller, Ocean Sciences

Michael A. Mischna, Planetary Sciences

Thomas H. Painter, Cryosphere Sciences

Roger A. Pielke Sr., Natural Hazards

Michael Poland, Geodesy

Eric M. Riggs, Education

Adrian Tuck, Nonlinear Geophysics

Sergio Vinciguerra, Mineral

and Rock Physics

Earle Williams, Atmospheric and Space Electricity

Mary Lou Zoback, Societal Impacts and Policy Sciences

Staff

Production: Faith A. Ishii, Production Manager; Melissa A. Tribur, Senior Production Specialist; Liz Castenson, Editor’s Assistant; Yael Fitzpatrick, Manager, Design and Branding; Valerie Bassett and Travis Frazier, Electronic Graphics Specialists

Editorial: Peter L. Weiss, Manager/Senior News Editor; Mohi Kumar, Scientific Content Editor; Randy Showstack, Senior News Writer; JoAnna Wendel, Writer

Marketing: Angelo Bouselli and Mirelle Moscovitch, Marketing Analysts

Advertising: Christy Hanson, Manager; Tel: +1-202-777-7536; Email: advertising@agu.org

©2015, American Geophysical Union. All Rights Reserved. Material in this issue may be photocopied by individual scientists for research or classroom use. Permission is also granted to use short quotes, figures, and tables for publication in scientific books and journals. For permission for any other uses, contact the AGU Publications Office.

Eos (ISSN 0096-3941) is published semi-monthly, on the 1st and 15th of the month except the 1st of January 2015 by the American Geophysical Union, 2000 Florida Ave., NW, Washington, DC 20009, USA. Periodical Class postage paid at Washington, D. C., and at additional mailing offices. POSTMASTER: Send address changes to Member Service Center, 2000 Florida Ave., NW, Washington, DC 20009, USA.

Member Service Center: 8:00 a.m.–6:00 p.m. Eastern time; Tel: +1-202-462-6900; Fax: +1-202-328-0566; Tel. orders in U.S.: 1-800-966-2481; Email: service@agu.org.

Use AGU’s Geophysical Electronic Manuscript Submissions system to submit a manuscript: <http://eos-submit.agu.org>.

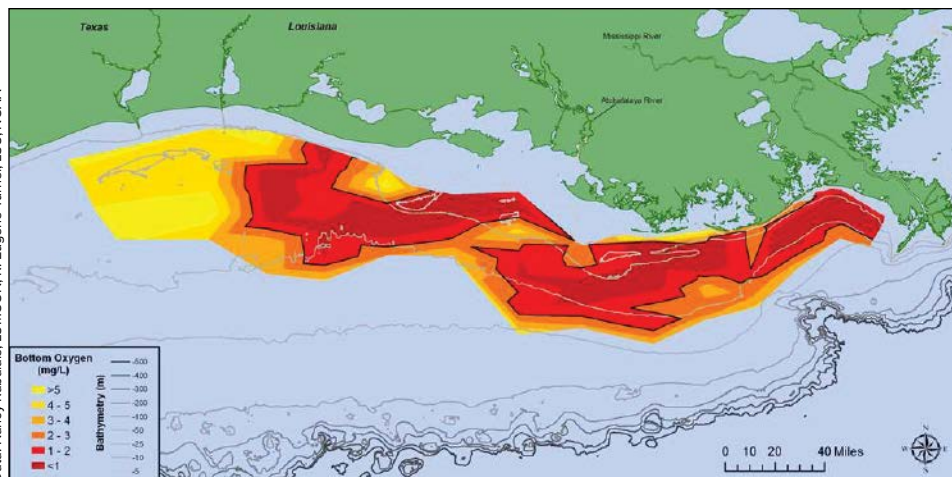
Views expressed in this publication do not necessarily reflect official positions of the American Geophysical Union unless expressly stated.

Christine W. McEntee, Executive Director/CEO

AGU
American Geophysical Union

Gulf of Mexico Dead Zone Largest Since 2002

Data: Nancy Rabalais, LUMCON; R. Eugene Turner, LSU, NOAA



Dissolved oxygen levels in the bottom water of the Gulf of Mexico off the Louisiana coast, plotted with data collected by a 28 July to 3 August survey cruise by the Louisiana Universities Marine Consortium. The measurements were used to help determine the size of this year's hypoxic (low-oxygen) zone, also known as the "dead" zone. Shades of red denote areas with oxygen concentrations of 2 milligrams per liter of water or less, the threshold below which waters are considered hypoxic.

This year's dead zone in the Gulf of Mexico spans 16,760 square kilometers—about the size of Rhode Island and Connecticut combined—making it the largest since 2002, when the Gulf dead zone stretched over 22,000 square kilometers.

Heavy June rains contributed to the larger-than-average size, said Nancy Rabalais, executive director of the Louisiana Universities Marine Consortium, who leads an annual survey cruise that measures the size and severity of the dead zone.

The 2015 dead zone extends more than 2500 square kilometers beyond what scientists forecast in May. The spring estimate fell short because abundant June precipitation in the Mississippi River watershed—mainly in Ohio and northern Mississippi—flushed more nutrients than expected into the river and caused much higher than average discharges during June and July from the river into the Gulf, Rabalais said.

Annual Dead Zone

Every spring, nitrogen- or phosphorus-laden compounds from fertilizers in the largest farming states run off into the Mississippi River, which empties into the Gulf of Mexico. The compounds, often referred to simply as "nitrogen" and "phosphorus," are nutrients

that foster large blooms of algae, which eventually die, fall to the bottom of the sea, and decompose, leaching oxygen from the water.

In the resulting oxygen-deficient environment, most living organisms cannot survive. Many simply flee the area, but others remain and perish, creating what's commonly known as a "dead zone."

In general, the Gulf of Mexico dead zone ranks as the second largest in the world, surpassed only by another vast stretch of depleted water in the Baltic Sea.

The National Oceanic and Atmospheric Administration forecasts the size of the Gulf dead zone each year on the basis of the quantities of nutrients that run off into the Mississippi River in May. This year the U.S. Geolog-

Using sustainable farming techniques or planting crops with deeper roots that retain nitrates can reduce nutrient runoff.

ical Survey estimated 104,000 metric tons of nitrate—a nitrogen-based nutrient—and 19,300 metric tons of phosphorus washed into the river during that month.

Lowering Nutrient Loads

Using sustainable farming techniques or planting crops with deeper roots that retain nitrates can reduce nutrient runoff in the Mississippi watershed, Rabalais said. Other measures, such as creating artificial wetlands at the ends of drainage systems to remove nitrates from water, can also help, she added.

This year's dead zone could have grown even larger than it did, especially off Texas, Rabalais said, except that westerly winds pushed low-oxygen water toward the east, shrinking the zone's footprint.

By JoAnna Wendel, Staff Writer

Earth's Future

AN OPEN ACCESS AGU JOURNAL

A transdisciplinary journal exploring global change



Now indexed in Web of Science

earthsfuture.agu.org

Geoscientists: Focus More on Societal Concerns

The year was 2004. The transformative event was the colossal Indian Ocean earthquake and tsunami. Watching the devastation unfold on television left Alik Ismail-Zadeh, an earthquake modeler, stunned by the depth of the tragedy and the realization that scientists knew enough about prior tsunamis in the region to have prompted protective measures, even though few—if any—such actions occurred.

“What am I doing, as a scientist with my models, if 200,000-plus people within a few minutes lost their lives?” Ismail-Zadeh recalled asking himself as he witnessed the destruction on TV. “Until 2004, I can tell you truly, I was involved in scientific problems related to society. But until 2004, I was more a pure scientist, a theoretician, than a scientist focusing on the needs of society.”

Today Ismail-Zadeh, whose expertise extends to other dynamics of Earth’s crust and interior, such as lava flows, is secretary general of the International Union of Geodesy and Geophysics (IUGG), a major global geosciences organization, and former chair of the Natural Hazards focus group of AGU, among other AGU roles.

In a recent interview, he told *Eos* that geoscientists need to think much more about the big-picture concerns facing society, even as they continue to work in their areas of expertise. Among the most pressing concerns in his view are climate change and other environmental problems, dwindling clean water resources, the need for environmentally friendly energy, and sustainability. To tackle those and other challenges, geoscientists need to work with social scientists, engineers, political scientists, and others, he said.

Applying Scientific Knowledge to Benefit Society

IUGG comprises eight semiautonomous associations with specialties in deep Earth interior, seismology, volcanology, the oceans, hydrological and cryospheric sciences, atmospheric sciences and meteorology, geo-

“What am I doing, as a scientist with my models, if 200,000-plus people within a few minutes lost their lives?”

magnetism and aeronomy, and geodesy. The union also includes several commissions, working groups, and services, many of them multidisciplinary, that “help to bring scientific knowledge closer to society,” Ismail-Zadeh explained. By fostering cooperation among international and intergovernmental organizations, IUGG helps convince governments to apply scientific knowledge for the betterment of societal issues, he added.

Eos interviewed Ismail-Zadeh in late June at IUGG’s General Assembly in Prague, Czech

Republic. IUGG is “a vibrant modern scientific union of nations and individual scientists,” Ismail-Zadeh told *Eos*. In his long-term vision of the organization, it “will promote research and science education linking scientific knowledge to societal needs and working toward a sustainable Earth.”

Moving from Scientific Statements to Action

During his conversation with *Eos*, Ismail-Zadeh repeatedly emphasized that natural hazards is a discipline in which geoscience can make a big difference. Ismail-Zadeh recently coauthored a paper in *Nature* about the need for the science of natural hazards to be less fragmented so that it can more effectively raise public awareness and influence policy efforts to increase resilience (see http://bit.ly/nature_Ismail-Zadeh).

“We should move from scientific statements to real actions,” he said. He cited a recent proposal by a transdisciplinary group of experts in disaster risk science established by the International Council for Science and the International Social Science Council. The proposal called for governments attending the March 2015 United Nations World Conference on Disaster Risk Reduction in Sendai, Japan, to establish a science-based assess-



A towering tsunami caused by a magnitude 9.1 earthquake on 26 December 2004 resulted in more deaths and injuries than any other tsunami in recorded history, according to the U.S. Geological Survey. Nearly 228,000 people died or vanished and were presumed dead. Men work at the remains of a housing complex in hard-hit Aceh province in Indonesia shortly after the disaster.

REUTERS/Steve Crisp



IUGG & C-IN

Alik Ismail-Zadeh, secretary general of the International Union of Geodesy and Geophysics, spoke at the organization's general assembly this summer in Prague, Czech Republic.

ment process for disaster risk reduction (see <http://bit.ly/RiskProposal>).

Envisioning a World with Fewer Disasters

"To understand disasters is not just to understand natural hazards," Ismail-Zadeh told *Eos*. "Disasters are not natural but social. If no people and infrastructure exist, there are no disasters."

The risk factors for disasters include physical vulnerabilities, such as construction quality of buildings, and social vulnerabilities, such as the behavior of people and their perception of risk, he said. Disasters occur also "because of ignorance, corruption, and irresponsibility. Psychologists, lawyers, the media, and others can contribute to solving the problems," he added.

Ismail-Zadeh said that he envisions a time when people live in "a better world" of low vulnerability and high resilience to extreme natural events.

"I dream that my great-grandson will show his children an exciting natural event, like a growing rupture of the crust or a moving tsunami wave or a rotating wind," Ismail-Zadeh said, referring to earthquakes and tornadoes, "and will do it from a balcony of his house, well-protected against natural hazards."

"My descendent will tell his children that 'scientists in the 21st century, including your great granddad, believed that natural events, which they called hazards, lead in many cases to tragedies in families and result in severe losses of lives and properties. They did not know well how to minimize or, as today, to eliminate disasters."

"We know it now. But we should thank them anyway that they thought about us and tried their best to reduce disasters and create a better future for us."

By **Randy Showstack**, Staff Writer

Guidelines Updated for Field Trip Guidebooks



Scientists at Utah's Moab Fault, discussing local geology.

Roy Luck, CC BY 2.0 (<http://bit.ly/ccby2-0>)

The Geoscience Information Society (GSIS) released in late July new guidelines for authors, editors, and publishers of geologic field trip guidebooks.

These guidebooks, used by researchers and educators, sometimes are the most current or only available description of an area's geology, but incomplete bibliographic information may make them hard to locate. The guidelines were last revised in 2005.

To create the new standards, GSIS looked at the format and content of each guidebook, including road logs, GPS coordinates, index maps, and illustrations, explained Linda

Musser, chair of the GSIS Guidebooks Standards Committee.

GSIS has also provided a free online aid, called *Geologic Guidebooks of North America*, to help locate specific field trip guidebooks. The database, compiled by GSIS members and supported by the American Geosciences Institute, includes more than 12,000 references.

The new set of guidelines and database can be accessed at <http://www.geoinfo.org/guidebooks.html>.

By **JoAnna Wendel**, Staff Writer

Get *Eos* highlights in your inbox every Friday.

To sign up for the *Eos Buzz* newsletter, simply go to publications.agu.org, scroll down, and enter your information in the "SIGN-UP FOR EOS BUZZ NEWSLETTER" section.

Monitoring Gas Emissions Can Help Forecast Volcanic Eruptions

5th Meeting of the Network for Observation of Volcanic and Atmospheric Change

Turrialba Volcano, Costa Rica, 27 April to 1 May 2015



Geoffroy Avard, OVSICORI

Maarten de Moor adjusts a scanning differential optical absorption spectroscopy instrument, mounted 2 kilometers from Costa Rica's smoldering Turrialba Volcano. The Observatorio Vulcanológico y Sismológico de Costa Rica maintains instruments like this one to continuously monitor sulfur dioxide emissions from the country's active volcanoes.

As magma ascends in active volcanoes, dissolved volatiles partition from melt into a gas phase, rise, and are released into the atmosphere from volcanic vents. The major components of high-temperature volcanic gas are typically water vapor, carbon dioxide, and sulfur dioxide.

Volcanologists have long recognized that measuring the chemical composition and emission rates of these discharged volatiles can help them understand the physical and chemical processes occurring within volcanic systems. However, in the past, continuous monitoring of gas emissions has been difficult because of the remote locations of many active volcanoes and the harsh environmental conditions at these sites.

In late April, 40 scientists collaborating in the Network for Observation of Volcanic and Atmospheric Change (NOVAC) gathered for the first time in 5 years. The meeting, held on Turrialba Volcano in Costa Rica, was intended to provide a platform for the exchange of experiences with NOVAC instrumentation, spectral evaluation, and data interpretation.

NOVAC Activities

NOVAC is currently the only international network of volcanic geochemical monitoring. Founded in 2005 by a European Union science project, the network's volcano observatories and university partners use scanning differential optical absorption spectroscopy instruments to continuously monitor volcanic sulfur dioxide emission rates.

To date, the consortium has installed 80 such instruments at 33 (~20%) of the world's most active volcanoes. The spectrometers measure the absorption of scattered solar ultraviolet radiation by sulfur dioxide in volcanic plumes. By scanning across the plume cross section, the instruments are able to measure the volcanic emission rate of sulfur dioxide from a safe distance from the vent.

What Limits Data Accuracy?

Meeting participants identified two main constraints on data accuracy: the availability of accurate wind speed information at the altitude of the volcanic plume and the ability

to derive accurate light path distributions in cases where clouds or aerosols scatter radiation into and out of the instrument field of view.

Solutions suggested at the meeting include using mesoscale wind modeling in regions surrounding the monitored volcanoes, implementing methods to retrieve wind speed from the spectroscopy data themselves, and applying sophisticated spectral analysis techniques to correct scattering effects.

The Value of Gas Emission Data

Despite the challenges, meeting participants unanimously agreed that the collected sulfur dioxide emission data greatly improved situational awareness of volcanic activity.

Case studies presented at sessions showed that emission rates were often correlated with explosive activity, in some cases preceding it by days or weeks. Information on magmatic processes could also be derived from the short-term variability of gas emissions, as well as their correlation with other measured geophysical parameters, such as seismicity or ground deformation.

The value of the NOVAC data for eruption forecasting and improving estimates of the global volcanic gas flux into the atmosphere makes expansion of the network to other high-threat volcanoes highly desirable, and the meeting participants agreed to seek support for this effort wherever possible.

Acknowledgments

The meeting was organized by the Volcano Disaster Assistance Program, a joint effort of the U.S. Geological Survey and the Office of U.S. Foreign Disaster Assistance, in collaboration with the Observatorio Vulcanológico y Sismológico de Costa Rica and the Sloan Foundation's Deep Carbon Observatory.

By **Christoph Kern**, Cascades Volcano Observatory, U.S. Geological Survey, Vancouver, Wash.; email: ckern@usgs.gov; **J. Maarten de Moor**, Observatorio Vulcanológico y Sismológico de Costa Rica, Heredia, Costa Rica; and **Bo Galle**, Chalmers University of Technology, Gothenburg, Sweden

How Can We Better Understand Low River Flows as Climate Changes?

Rivers—the lifeblood of society—face unprecedented threats from the world’s changing climate. In particular, scientists expect that rivers in many regions will run lower than ever before and for longer spans of time.

In light of this, the study of low river flows, or low-streamflow hydrology, is critically important to society. A firm understanding of low-streamflow hydrology can help resource specialists manage, for example, municipal water supply, irrigation, industry allocations, river navigation, recreation, and wildlife conservation [Smakhtin, 2001].

Despite how low flow has direct ties to water scarcity and drought, relatively few studies evaluate how climate change will affect low flows. Low-flow studies have typically been grounded in the principle of stationarity—the idea that natural systems vary within a known, unchanging range of variability.

But this assumption no longer holds given that climate change has raised average temperatures to extreme highs not seen in mil-

lions of years [Milly *et al.*, 2008]. We urgently need a better understanding of the changing behavior of low-flow conditions to inform sustainable water management and protect against potential risks and impacts.

The Challenge of Low Flow

The limited research on the phenomenon of low flow can be partially attributed to its unique challenges. First, there is the data challenge: Many basins lack hydrological monitoring stations, and human activities such as filling and drawing down reservoirs and extracting water for irrigation can affect data quality. Next, low flows are strongly influenced by groundwater interactions with surface water, for which data are difficult to obtain. Analyses therefore rely on models.

Finally, what someone defines as “low flow” will vary depending on water needs. For example, farmers, ranchers, and water resource planners may be concerned with average 7-day or 30-day minimum flow, whereas city planners and engineers may be

interested in a particular exceedance probability threshold (e.g., the low flow occurred 25%, 10%, or 5% of the time).

Several tools can shed light on these issues from both scientific and policy-making perspectives. Each has shortcomings that we must work steadily to improve. But together they can advance the science of low flows so that water managers can make more informed decisions.

The Power of Hydrological Models

The first tool beyond the raw data scientists should turn to when studying low flows is hydrological models—computer simulations of water movement in the environment. These models incorporate characteristics of the land surface, such as the topography, vegetation, and soil. They also include the physical processes that govern the amount of water going in and out of the land, such as soil moisture, evaporation, plant transpiration, and runoff.

Such models already allow scientists to address changes in land use. But by combining these parameterizations with precipitation and temperature information, they can also assess low flow under changing climates.

These models can also partially alleviate issues with data availability. First, they work over areas with limited data coverage, interpolating over regions with missing data. They



A dead fish on the dry bed of the Rio Grande in Albuquerque, N.M., emphasizes the ecological risks posed by low river flows.

also offer a means to reconstruct data that are altered by humans via reservoirs and irrigation, predicting the “natural” flow by simulating streamflows solely on the basis of meteorology. Such predictions are important given that our inspection of more than 9000 U.S. Geological Survey (USGS) stream gauges in the continental United States revealed that more than three-fourths of them have been altered by reservoir storage.

Finally, if one wants to consider the impacts of changing land cover, physically based models offer the only way to estimate future low flows on the basis of future climate change projections.

Although a limited number of studies have successfully used hydrological models for low-flow research [e.g., Wilby and Harris, 2006; Demirel et al., 2013] and some have even included changing climate conditions [Vaze et al., 2010], the potential remains largely untapped.

Room for Improvement

Second, although scientists have done a lot of work to calibrate hydrologic models under average flow conditions or even in flood scenarios, they have done very little work to attempt to calibrate their models when rivers and streams run low. Model calibration is already limited by the availability of high-quality data and therefore involves some reconstruction of regions with missing data. This process, called regionalization, fills in empty regions with parameters from nearby basins or basins that have similar physio-

Low-flow studies have typically been grounded in the principle of stationarity. But this assumption no longer holds.

graphic features (e.g., topography, vegetation, soils).

Scientists often use regionalization to estimate how often rivers flood but do not have an analogous approach to calibrate predictions of how often they run dry. Most efforts, including those of the USGS, are focused on average conditions. But we think that a comparable approach could be developed for low-flow characteristics, which would be a great improvement.

Accounting for a Changing Climate

The impact of climate on low river flows is visible both today and in the historical record on time scales as small as decades [Lins and Slack, 1999]. Further, low flows are influenced by recurring climate cycles due to fluctuations in the ocean-atmospheric system, such as the El Niño–Southern Oscillation and the Pacific Decadal Oscillation.

Therefore, an integral part of investigating nonstationarity in low-flow features also lies in identifying the influence of climate vari-

ability at decadal to multidecadal scales, as previous studies have indicated [Stahl and Hisdal, 2004]. However, for many stream gauge locations, for example, in the United States and elsewhere, data are available for only a limited number of years, which may not span the recurrence interval and duration of such fluctuations.

Once studies specifically address how climate influences low river flow on broad to local scales, the research community needs to develop a way to incorporate those findings into how it designs and reports indices of low flow. This step is critical because current estimates of low-flow characteristics do not reflect these shifting risks—rather, they are “stationary.”

For instance, one of the most common low-flow indices in the United States is the minimum flow that occurs, on average, every 10 years, as measured over a 7-day period (10q7). Originally developed to regulate stream pollution in the 1970s, 10q7 has since been used widely in hydrology.

However, because of periodic shifts in the ocean-atmosphere system and because the Earth’s climate is entering new territory, the current practice of estimating a single 10q7 value may be inappropriate because it does not accurately reflect the shifting risk.

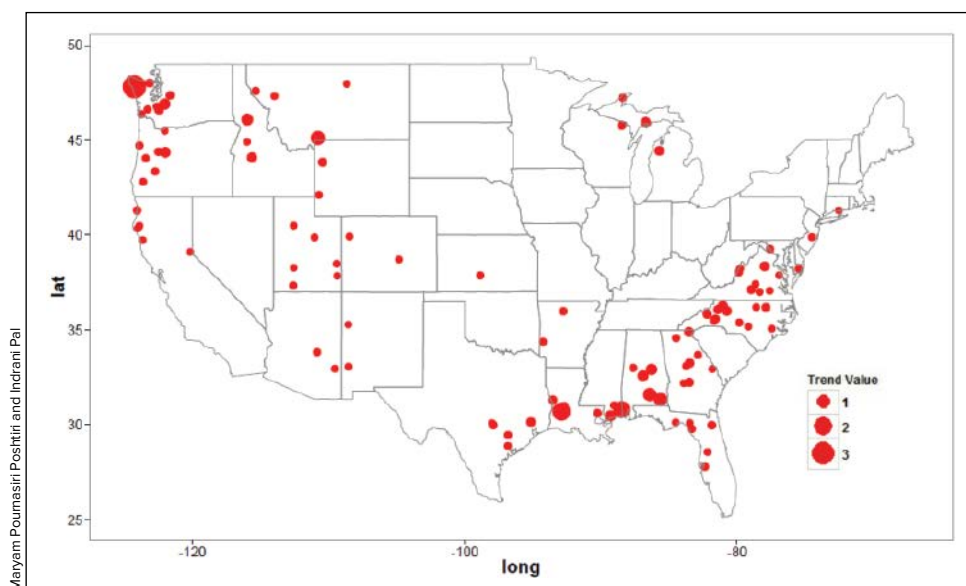
One tool that can be applied to this issue is extreme value theory [Coles, 2001], a branch of statistics uniquely geared toward modeling minimum (or maximum) values. Extreme value theory is well suited to studying extremes in hydrology [Katz et al., 2002] because it develops techniques to model extreme events rather than average conditions.

Scientists have already used extreme value theory to look at changing low flows in Europe [Feyen and Dankers, 2009]. The tool also offers a means to include trends or climate information such as El Niño to quantify how minimum flows vary from year to year. Incorporating trends or climate indices has not been done in the study of low flows but offers a promising new way to account for nonstationarity.

Connecting Scientists with Policy Makers

To truly advance low-flow science in a changing climate, research directions and outcomes must also reflect the needs and concerns of decision makers. The successful use of climate knowledge requires some iteration between the scientists who produce knowledge and those who must use it to make decisions and set policies [Dilling and Lemos, 2011].

Several research initiatives in this vein are building the capacity to prepare for and adapt to climate variability and change, such as the Western Water Assessment, one of the National Oceanic and Atmospheric Administration’s Regional Integrated Sciences and



Locations of stream systems that may soon experience significantly low flows. Color bubbles indicate location of the stations and loss-of-flow estimates in cubic feet per second per day per year. The size of the bubble is proportional to the magnitude of trend value. The image was generated using data from the U.S. Geological Survey’s Hydro-Climatic Data Network.

To truly advance low-flow science in a changing climate, research directions and outcomes must also reflect the needs and concerns of decision makers.

Assessments. This and other key efforts aim to develop closer partnerships between scientists and engineers [Tye *et al.*, 2015] and are prime examples that can guide future low-flow research.

We challenge the scientific community, together with engineers, regional water managers, local drought planners, and state agencies, to more actively engage in low-flow discourse. Only together can we advance the science of low flows, develop tools to manage the changing risks of low flows, and achieve sustainable water management in a changing climate.

Acknowledgments

The National Center of Atmospheric Research is funded by the National Science Foundation, and support for E.T. was provided by NSF award 1048829. We extend our thanks to

Maryam Pournasiri Poshtiri for helping us create the map.

References

- Coles, S. (2001), *An Introduction to Statistical Modeling of Extreme Values*, 208 pp., Springer, London.
- Demirel, M. C., M. J. Booij, and A. Y. Hoekstra (2013), Effect of different uncertainty sources on the skill of 10 day ensemble low flow forecasts for two hydrological models, *Water Resour. Res.*, 49(7), 4035–4053, doi:10.1002/wrcr.20294.
- Dilling, L., and M. C. Lemos (2011), Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy, *Global Environ. Change*, 21(2), 680–689.
- Feyen, L., and R. Dankers (2009), Impact of global warming on streamflow drought in Europe, *J. Geophys. Res.*, 114, D17116, doi:10.1029/2008JD011438.
- Katz, R. W., M. B. Parlange, and P. Naveau (2002), Statistics of extremes in hydrology, *Adv. Water Resour.*, 25, 1287–1304.
- Lins, H. F., and J. R. Slack (1999), Streamflow trends in the United States, *Geophys. Res. Lett.*, 26(2), 227–230.
- Milly, P. C. D., J. Betancourt, M. Falkenmark, R. M. Hirsch, Z. W. Kundzewicz, D. P. Lettenmaier, and R. J. Stouffer (2008), Climate change: Stationarity is dead: Whither water management?, *Science*, 319, 573–574.
- Rosenberg, E. A., E. A. Clark, A. C. Steinemann, and D. P. Lettenmaier (2012), On the contribution of groundwater storage to interannual

streamflow anomalies in the Colorado River basin, *Hydrol. Earth Syst. Sci. Discuss.*, 9(1), 1475–1491.

Smakhtin, V. (2001), Low flow hydrology: A review, *J. Hydrol.*, 240(3–4), 147–186.

Stahl, K., and H. Hisdal (2004), *Hydroclimatology, in Hydrological Drought: Processes and Estimation Methods for Streamflow and Groundwater*, Dev. Water Sci., vol. 48, edited by L. M. Tallaksen and H. Van Lanen, pp. 19–51, Elsevier, Amsterdam.

Towler, E., M. Roberts, B. Rajagopalan, and R. Sojda (2013), Incorporating probabilistic seasonal climate forecasts into river management using a risk-based framework, *Water Resour. Res.*, 49, 4997–5008, doi:10.1002/wrcr.20378.

Tye, M. R., G. Holland, and J. M. Done (2015), Rethinking failure: Time for closer engineer-scientist collaborations on design, *Proc. Inst. Civ. Eng. Forensic Eng.*, doi:10.1680/feng.14.00004.

Vaze, J., D. A. Post, F. H. S. Chiew, J. M. Perraud, N. R. Viney, and J. Teng (2010), Climate non-stationarity—Validity of calibrated rainfall-runoff models for use in climate change studies, *J. Hydrol.*, 394(3), 447–457.

Wilby, R. L., and I. Harris (2006), A framework for assessing uncertainties in climate change impacts: Low-flow scenarios for the River Thames, UK, *Water Resour. Res.*, 42, W02419, doi:10.1029/2005WR004065.

By **Indrani Pal**, Department of Civil Engineering, College of Engineering and Applied Science, University of Colorado, Denver; email: indrani.pal@ucdenver.edu; **Erin Towler**, National Center of Atmospheric Research, Boulder, Colo.; and **Ben Livneh**, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder

AGU Author Webinar: How to Publish Your Research

9 October 2015 • 2:00 p.m. EDT

Attend this 60-minute webinar to hear AGU editors discuss the benefits of publishing with AGU, how to navigate the peer-review process, and review AGU's guide to publication ethics.

Register today to hear from

Mary-Elana Carr, Editor, *Global Biogeochemical Cycles*

Brooks Hanson, Director of Publications, American Geophysical Union


Robert Pincus, Editor in Chief, *Journal of Advances in Modeling Earth Systems* (JAMES)



Register at **wileyauthors.com/webinars**

AGU PUBLICATIONS

WHAT LIES DEEP

A dramatic photograph of a volcanic landscape. In the foreground, dark, jagged lava rocks are illuminated by bright, glowing orange and red lava flows that seep through cracks and crevices. The lava flows create a stark contrast with the dark, textured rocks. In the background, a hazy, overcast sky with soft, grey clouds stretches across the horizon. The overall mood is one of raw, powerful geological activity.

in the Mantle Below?

By Gillian R. Foulger, Giuliano F. Panza, Irina M. Artemieva, Ian D. Bastow, Fabio Cammarano, Carlo Doglioni, John R. Evans, Warren B. Hamilton, Bruce R. Julian, Michele Lustrino, Hans Thybo, and Tatiana B. Yanovskaya

Fresh lava oozes from vents in Hawaii's Kilauea Volcano.

Deep within Earth's interior, in the brittle lithosphere and in the viscous asthenosphere below it, magma collects and ultimately feeds erupting volcanoes on Earth's surface. This magma holds keys to understanding the processes that create island chains like Hawaii.

However, scientists can map the mantle—or any part of Earth's interior—only by using remote sensing techniques. The most important such technique is seismic tomography.

Similar to medical computerized tomography (CT) scanning, seismic tomography allows scientists to construct three-dimensional images of deep Earth from observations of seismic waves that have passed through it. The

speed of these waves varies depending on the composition, phase, temperature, and pressure of the material through which they travel. Analyzing seismic waves can thus reveal details of these deep materials. Were it not for seismology, we would be almost totally ignorant of the structure of the deep interior of Earth.

The term “seismic tomography” was first coined by Adam Dziewonski and Don L. Anderson [*Dziewonski and Anderson, 1984*]. Over subsequent decades, the method has received substantial research funding, and the results have profoundly influenced our knowledge of Earth's structure and dynamics.

Nevertheless, communicating the technique's limitations between subdisciplines within Earth science remains a challenge. For reasons of space and other factors, pub-



lished papers often tend to deemphasize important caveats [Foulger *et al.*, 2013]. The bottom line is that scientists tend to underestimate pitfalls and often have disproportionate faith in results.

Teleseismic Tomography

Scientists apply seismic tomography on scales ranging from small crustal features a few kilometers across to the entire mantle, which is some 3000 kilometers thick. A method commonly used to study regions up to a few hundreds of kilometers wide and deep, referred to as teleseismic tomography, typically has a resolution on the order of 10 kilometers.

Teleseismic tomography analyzes the relative arrival times at surface seismometers of seismic waves from distant earthquakes that have traveled through the interior of Earth. Seismic waves slow down when traveling through some materials (e.g., iron-rich rocks, partially molten material, or hot rock), and as a result, some waves reach seismic monitoring stations slightly delayed. Scientists then convert these timing delays to information about wave speeds in the material through which the seismic waves passed.

Over the past 3 decades, scientists have made enormous progress in assembling software and data for teleseismic tomography. They have developed sophisticated inversion programs and established large equipment pools, enabling practitioners to deploy hundreds of stations in dense arrays. They have also densified national and global seismic networks and greatly improved their quality.

Thanks to this progress, model resolution significantly improved. Nevertheless, important challenges remain—some technical and some involving the way we communicate science.

Limitations of Teleseismic Tomography

Teleseismic tomography, although sensitive to horizontal variations in seismic wave speed, has virtually no ability to determine vertical (depth) variations. This defect stems from relying exclusively upon rays that sample all depths in the same way. Arbitrary changes in wave speeds throughout a horizontal slab produce only minuscule variations in the predicted relative arrival times and thus are virtually undetectable. Among other things, this fact means that scientists cannot establish the vertical continuity of tomographic anomalies with certainty.

Teleseismic tomography, although sensitive to horizontal variations in seismic wave speed, has virtually no ability to determine depth variations.

Another reason researchers cannot determine the true depth extent of imaged structures is that the incoming seismic waves arrive traveling steeply upward because they have been refracted toward the surface by the increase of wave speed with depth in Earth. The resulting strongly nonuniform ray distribution causes vertical smearing in tomographic images and gives distorted pictures that often contain spurious pipe-like features.

Compounding these problems, researchers commonly display structures derived as differences relative to one-dimensional models of the (unknown) local average wave speeds. This practice makes it difficult for readers to com-

pare results from different regions [Bastow, 2012]. Alternatively, results may be shown relative to an assumed average global model, but this conceals major global features such as the seismic low-velocity zone, a layer in the shallow mantle

thought to represent the asthenosphere [Thybo, 2006].

In all tomography methods, the strengths of calculated anomalies depend heavily on subjective choices of the inversion parameters used, such as those involving damping or smoothing. Despite this, researchers still commonly assume that the relative strengths of resulting anomalies are accurate.

Scientists often unjustifiably interpret these strengths as direct reflections of the temperature of material through which the seismic waves have passed. Widely used assumptions hold that high wave speeds correspond to cold, probably dense and sinking material and low velocities correspond to hot, rising material. However, these assumptions cannot be made because variations in composition and degree of contained partial melt (which is strongly related to hydrogen and carbon content) have larger effects on seismic wave speed than temperature. In some unusual cases where scientists checked the assumptions independently, these assumptions proved to be false [e.g., Trampert *et al.*, 2004].

Researchers need an even greater leap of faith to deduce convective motion. Tomography can only reveal instantaneous (on a geological timescale) snapshots of the structure of the mantle, not its internal motion.

Difficulties in Assessing the Reliability of Results

Scientists make great efforts to assess the reliability of their results, but such assessments are not easy. Common tests of model integrity prove unreliable because they are limited

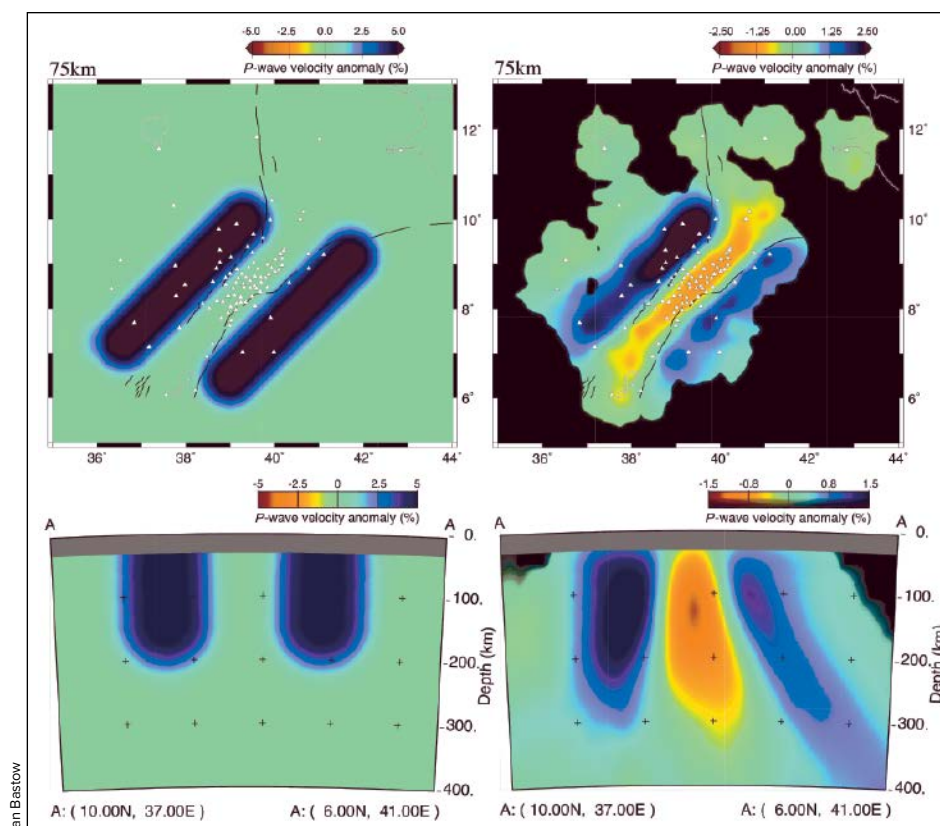


Fig. 1. Theoretical mantle structure model compared with corresponding tomographic images for Africa's Afar region, where the African plate is splitting in two. (top left) A theoretical model that consists of two regions of high wave speed flanking the rift in the upper mantle. (top right) A relative arrival time tomographic result obtained by analyzing seismic waves that would pass through such a theoretical model. A strong low-velocity feature, which is an artifact of the analysis method, appears in the well-resolved region between the two high-velocity flanks. Conversely, an input model consisting of only a slow wave speed anomaly beneath the rift would result in erroneously fast wave speed rift flanks. (bottom) Cross-sectional views of (left) the theoretical model and (right) the tomographic result.

to the mathematical approach used and fail to address several significant sources of error (Figure 1) [Foulger et al., 2014; Léveque et al., 1993; van der Hilst et al., 1993].

The scientific community cannot assess the absolute accuracy of a result because no method exists that can provide superior results against which the results of teleseismic tomography can be compared. Furthermore, scientists cannot really know whether the method as used answers the question that the researchers intended (known as “epistemic” uncertainty).

The next best thing involves examining the repeatability of independent studies. However, scientists typically don't perform multiple tomography studies covering the same locality. Even if they do, experiments are not usually completely independent. Such experiments often draw data

from the same pool, and the mathematical methods and computer programs used may be related.

The Mantle Plume Controversy: Do Plumes Even Exist?

A few volcanic regions, however, have been the subjects of multiple tomography studies. Scientists find these areas particularly interesting—some postulate that they are fueled by an elusive theoretical phenomenon: deep mantle plumes.

These regions, which include Hawaii and Yellowstone, are puzzling because they lie far from the boundaries of tectonic plates where most igneous activity occurs. The plume hypothesis proposes that they are fed by columns of hot, solid rock a few tens or hundreds of kilometers in diameter rising from the core-mantle boundary and inde-

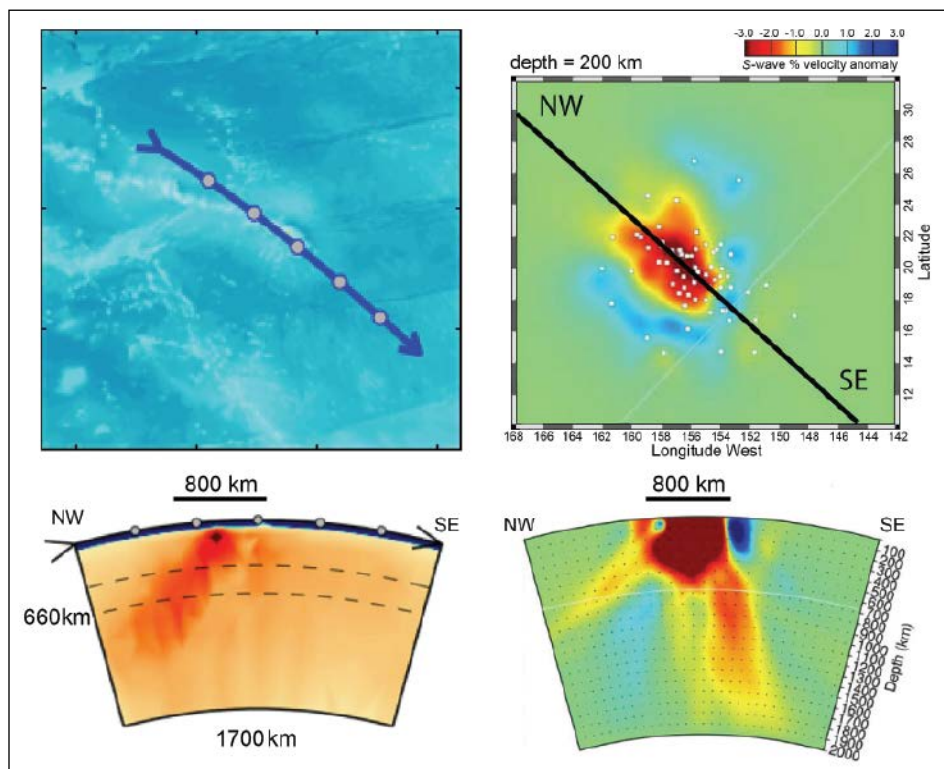


Fig. 2. Lack of repeatability in recent studies of Hawaii: (left) from Li et al. [2008], showing a low-velocity body, interpreted as a plume, tilting from the Big Island of Hawaii to the northwest beneath the Hawaiian island chain; (right) from Wolfe et al. [2009], showing a similar low-velocity body, also interpreted as a plume, except tilting in the exact opposite direction—from beneath the Big Island of Hawaii to the southeast.

pendent of the convection involved in plate tectonics. Scientists expect that deep mantle plumes, if they exist, should be visible in tomographic images as columnar regions of low seismic wave speed.

During the past decade, new observations have thrown the existence of mantle plumes into serious doubt. Predictions of the hypothesis—such as the updoming of Earth's surface and flood volcanism when a plume eruption begins—seldom are confirmed by observation [Foulger, 2010]. As a result, many ongoing studies attempt to scrutinize the hypothesis against observations.

Hawaii, the archetypal candidate for the location of a deep mantle plume, thus becomes an important target for observations. If the existence of a plume under Hawaii could be confirmed or ruled out, it could help settle the debate regarding whether or not plumes exist in general.

Unfortunately, Hawaii is extraordinarily poorly placed for study, with a relatively small landmass and few nearby earthquake sources. Teleseismic tomography experiments typically cannot probe deeper than the aperture of the

seismometer network used. As a result, only the upper few hundred kilometers of the mantle beneath Hawaii can be reliably imaged; seismic tomography cannot reach down a few thousand kilometers, where plumes are thought to originate. Recent studies exhibit little repeatability, even at shallow depths below Hawaii (Figure 2).

The Yellowstone Opportunity

Yellowstone is in a very different situation. It lies in a continental setting, and researchers can deploy extensive, optimized seismic networks relatively easily. As a result, scientists have targeted it for numerous ambitious experiments since the 1970s.

The culmination of these projects is the roughly \$500 million, 2000-site USArray seismic network, which covers the entire United States. Many tomographic studies of the Yellowstone region use the superb data it has collected (see Pavlis et al. [2012] for a review). These studies provide the best opportunity currently available to study the repeatability of teleseismic tomography for a proposed plume region.

The results show broad agreement regarding bodies on a scale of several tens of kilometers. These include the sinking Farallon slab—a “lost” tectonic plate that became completely subsumed within the mantle over the past 15 million years or so. Today the slab exhibits high wave speeds, partly because it is colder and more rigid than the surrounding mantle.

Researchers also see a strong, shallow, low-wave speed anomaly beneath the Eastern Snake River Plain and Yellowstone and high wave speeds farther east beneath the central United States. However, repeatability deteriorates for smaller bodies and with increasing depth from about 200 to 1000 kilometers.

Remarkably, because of the lack of repeatability between results at depths greater than 200 kilometers, this work has brought no consensus regarding the shape, location, continuity, or depth extent of seismic wave speed anomalies directly beneath Yellowstone, nor has it resolved whether a mantle plume exists below the crust [Foulger *et al.*, 2015]. If teleseismic tomography cannot settle the debate at an ideally located and monitored place such as Yellowstone, the question arises as to whether it can do so anywhere.

The Future of Teleseismic Tomography

Seismic tomography—an immensely powerful tool that deserves its recent popularity—shines a light on the mantle, influencing almost every branch of Earth science.

However, the greatest remaining challenge may lie not in doing better tomography but in appreciating its limitations and living with the results. Tomography models need to be shared within the Earth science community in a way that communicates not only the results’ robust features but also their real errors [Panza *et al.*, 2007].

Seismic tomography results also need to be interpreted jointly with other data, including gravity studies and tectonic reconstructions. The research community needs such interdisciplinary work to reduce ambiguities in interpretation.

Researchers often turn to the geochemistry of surface samples to back up interpretations, but this approach is much less helpful than commonly assumed. The geochemical compositions of igneous rocks at the surface cannot be used to infer deep mantle plumes or to assess the composition and convective motion of the deep mantle. Moreover, any attempts at geochemical “ground truthing” have only limited power to estimate the temperature of the melting mantle sources that feed surface volcanism [Lustrino and Anderson, 2015].

Understanding what is not reliable in a seismic tomography image and interpreting what is reliable in terms of geology thus remain perhaps our most exciting current challenges.

References

- Bastow, I. D. (2012), Relative arrival-time upper-mantle tomography and the elusive background mean, *Geophys. J. Int.*, **190**, 1271–1278.
- Dziewonski, A. M., and D. L. Anderson (1984), Seismic tomography of the Earth’s interior, *Am. Sci.*, **72**, 483–494.
- Foulger, G. R. (2010), *Plates vs Plumes: A Geological Controversy*, 328 pp., Wiley-Blackwell, Chichester, U. K.
- Foulger, G. R., *et al.* (2013), Caveats on tomographic images, *Terra Nova*, **25**, 259–281.
- Foulger, G. R., *et al.* (2014), Caveats on tomographic images, paper presented at European Geosciences Union General Assembly, Vienna, Austria, 27 April to 2 May.
- Foulger, G. R., R. L. Christiansen, and D. L. Anderson (2015), The Yellowstone ‘hot spot’ track results from migrating Basin Range extension, in *The Interdisciplinary Earth: A Volume in Honor of Don L. Anderson*, edited by G. R. Foulger, M. Lustrino, and S. D. King, Geol. Soc. of Am., Boulder, Colo., in press.
- Léveque, J. J., L. Rivera, and G. Wittlinger (1993), On the use of the checker-board test to assess the resolution of tomographic inversions, *Geophys. J. Int.*, **115**, 313–318.
- Li, C., R. D. van der Hilst, E. R. Engdahl, and S. Burdick (2008), A new global model for *P* wave speed variations in Earth’s mantle, *Geochim. Geophys. Geosyst.*, **9**, Q05018, doi:10.1029/2007GC001806.
- Lustrino, M., and D. L. Anderson (2015), The mantle isotopic printer: Basic mantle plume geochemistry for seismologists and geodynamists, in *The Interdisciplinary Earth: A Volume in Honor of Don L. Anderson*, edited by G. R. Foulger, M. Lustrino, and S. D. King, Geol. Soc. of Am., Boulder, Colo., in press.
- Panza, G. F., A. Peccerillo, A. Aoudia, and B. Farina (2007), Geophysical and petrological modelling of the structure and composition of the crust and upper mantle in complex geodynamic settings: The Tyrrhenian Sea and surroundings, *Earth Sci. Rev.*, **80**, 1–46.
- Pavlis, G. L., K. Sigloch, S. Burdick, M. J. Fouch, and F. L. Vernon (2012), Unraveling the geometry of the Farallon plate: Synthesis of three-dimensional imaging results from USArray, *Tectonophysics*, **532–535**, 82–102.
- Thybo, H. (2006), The heterogeneous upper mantle low velocity zone, *Tectonophysics*, **416**, 53–79.
- Trampert, J., F. Deschamps, J. Resovsky, and D. Yuen (2004), Probabilistic tomography maps chemical heterogeneities throughout the lower mantle, *Science*, **306**, 853–856.
- van der Hilst, R., E. R. Engdahl, and W. Spakman (1993), Tomographic inversion of *P* and *pP* data for aspherical mantle structure below the northwest Pacific region, *Geophys. J. Int.*, **115**, 264–302.
- Wolfe, C. J., S. C. Solomon, G. Laske, J. A. Collins, R. S. Detrick, J. A. Orcutt, D. Bercovici, and E. H. Hauri (2009), Mantle shear-wave velocity structure beneath the Hawaiian hot spot, *Science*, **326**, 1388–1390.

Author Information

Gillian R. Foulger, Department of Earth Sciences, Durham University, Durham, U. K.; email: g.r.foulger@durham.ac.uk; **Giuliano F. Panza**, Department of Mathematics and Geosciences, University of Trieste, Trieste, Italy; also at Structure and Non-Linear Dynamics of the Earth, International Center for Theoretical Physics, Trieste, Italy, and the Institute of Geophysics, China Earthquake Administration, Beijing, China; **Irina M. Artemieva**, Department of Geography and Geology, University of Copenhagen, Copenhagen, Denmark; **Ian D. Bastow**, Department of Earth Science and Engineering, Imperial College, London, U. K.; **Fabio Cammarano**, Department of Geography and Geology, University of Copenhagen, Copenhagen, Denmark; **Carlo Doglioni**, Dipartimento Scienze della Terra, Università Sapienza, Rome, Italy; **John R. Evans**, Earthquake Science Center, U.S. Geological Survey, Santa Cruz, Calif; **Warren B. Hamilton**, Department of Geophysics, Colorado School of Mines, Golden; **Bruce R. Julian**, Department of Earth Sciences, Durham University, Durham, U. K.; **Michele Lustrino**, Dipartimento di Scienze della Terra, Università degli Studi di Roma La Sapienza, Rome, Italy; **Hans Thybo**, Department of Geography and Geology, University of Copenhagen, Copenhagen, Denmark; and **Tatiana B. Yanovskaya**, Department of Physics of the Earth, Saint Petersburg State University, Saint Petersburg, Russia

A Weather Eye on

By F. M. Monaldo, C. R. Jackson, W. G. Pichel, and X. Li



A fisherman working on deck in the Bering Sea, buffeted by 50-knot winds.



Coastal Winds

Along the Alaskan coast, strong, low-level winds flow through mountain gaps and high-walled bays. These “gap flow winds” can vary dramatically over short distances, and they present a significant hazard to boats and aircraft.

The National Oceanic and Atmospheric Administration (NOAA) now has the capability to map these winds and other localized wind patterns over the ocean using satellite imagery created by synthetic aperture radar (SAR). Using this capability, NOAA developed a data product called SAR Winds, which provides daily updates of gap flow wind speeds over the polar regions. SAR Winds also provides updates of wind speeds along other U.S. coasts but only when satellite data for those locations are available.

But creating daily maps of wind patterns over Alaska is just the beginning: SAR Winds aims to provide near-real-time data for all U.S. coasts. Armed

With the data, coastal managers can better anticipate hazards and risks, monitor pollution spills, and coordinate search and rescue efforts.

with these data, coastal managers can better anticipate hazards and risks, monitor pollution spills, and coordinate search and rescue efforts.

From Radar Reflections to Wind Speeds

High-resolution radar imagery requires large antennas. SAR systems are typically mounted on an aircraft or satellite. They create the equivalent of a very large aperture by recording the reflected radar data while in flight.

Two phenomena are key to translating radar images to wind speed measurements. First, the ocean becomes rougher as wind speed increases, and the roughness is aligned with the wind direction. Second, as the ocean surface gets rougher, the radar reflectivity increases. One measure of this reflectivity is the normalized radar cross section (NRCS) [Wright, 1960].

Geophysical model functions relate wind speed and direction to the corresponding NRCS [Stoffelen and Anderson, 1997; Hersbach, 2010]. In these model functions, a specific NRCS measurement can correspond to several different wind speed and direction pairs. However, if wind direction is known, the wind speed can be computed from the NRCS value. The SAR wind processing uses the wind direction from a numerical weather model to uniquely identify the wind speed for a measured NRCS.

Building from a Long History

The measurement of wind speed from SAR imagery enjoys a long heritage. Wind speed data were inferred from the Seasat SAR, the first civilian spaceborne SAR, launched in 1978 [Weissman *et al.*, 1979].

From 1995 to 2010, NOAA used imagery from Canada's Radarsat-1 to regularly derive wind speed maps as part of its Alaska SAR Demonstration Project (1999), where Radarsat-1 data were downloaded at the Alaska Satellite Facility in Fairbanks and processed into wind speed maps within a few hours from acquisition. This project permitted the validation of SAR wind speed measurements against both buoy and NASA's QuikSCAT scatterometer measurements, showing a standard deviation smaller than 2 meters per second [Monaldo *et al.*, 2004].

SAR Winds builds from this long history. Through the SAR Winds system, NOAA produces high-resolution maps of wind speeds over the ocean. These maps can image features down to a resolution of 500 meters.

At this resolution, SAR Winds observes fine-scale wind patterns on the surface of the ocean at the coasts. The high resolution reveals features not observable in other data sets or represented in current models.

SAR Winds became NOAA's first operational SAR-based product in May 2013. Operational here means that the product has a demonstrated set of users and that NOAA makes special efforts to maintain availability and provide the data in as near real time as possible.

An Abundance of Images

SAR Winds first started making maps of Alaska's coast using SAR imagery from Canada's Radarsat-2, obtained by NOAA's National Ice Center (NIC). NIC monitors the polar sea ice extent and determines associated ice hazards to navigation. NIC's Radarsat-2 imagery yields about 4000 images per year—these images are sent to SAR Winds for further processing to make them user friendly. Then they are distributed by NOAA's Office of Satellite and Product Operations.

SAR Winds will take advantage of the large volume of SAR imagery expected from the European Space Agency's (ESA) Sentinel-1 satellites. Sentinel-1A, which launched 3 April 2014, acquires approximately 26 minutes of imagery during each orbit. An identical Sentinel-1B SAR satellite is slated for launch in 2016.

ESA has a "free and open" data policy for Sentinel-1 imagery. Since October 2014, ESA has made available "preliminarily qualified" Sentinel-1A imagery via its public Scientific Data Hub. Roughly 100 images a day are being converted to SAR Winds products for system evaluation and product validation. Thus far, Sentinel-1A observations, when integrated into SAR Winds, perform with an accuracy similar to that of the Radarsat-2 data.

In the future, NOAA anticipates becoming an international partner of the Sentinel satellites and obtaining Sentinel-1A imagery via a high-speed data link to support SAR Winds processing with near-real-time delivery of around 3 hours. NOAA's initial priority is to produce SAR Winds products for Sentinel-1A data acquired within 500 kilometers of the U.S. coasts, over the Great Lakes, and in the polar regions.

Wind Maps off Alaska's Coast

Currently, the principal output of SAR Winds is a Network Common Data Form (NetCDF) file that's climate-forecast compliant, meaning that it contains an agreed-upon set of metadata that promotes sharing and use of geophysical information.

The file includes layers for SAR-derived wind speed, Global Forecast System (GFS) model wind speed and direction, a land mask, longitude, latitude, radar look direction, and incident angle.

Images produced over the Arctic region include an ice mask layer from the Interactive Multisensor Snow and Ice Mapping System [Helfrich *et al.*, 2007]. The ice mask assists in validation by flagging locations where wind speeds are derived from ice pixels rather than over the ocean. Wind speeds over ice masses can be excluded from the calculations using the mask.

For a sample SAR Winds map, see Figure 1. The National Weather Service, especially local forecast offices in the Alaska region, has taken an interest in using images from SAR Winds, such as those similar to Figure 1. These offices

use the SAR Winds images to assist analysts in their forecasts.

Validating Operational Products

Validation is an important component of the operational SAR Winds system. SAR wind speed accuracy is estimated by comparing the retrieved SAR winds against independent wind speed estimates.

For the period between 21 December 2014 and 17 March 2015, 87,497 comparisons were made between Sentinel-1A-derived SAR winds and spatially coincident wind retrievals from NOAA's Advanced Scatterometer (ASCAT; taken within ± 2 hours of the Sentinel-1A observation time). Most of these comparisons were in polar regions at latitudes north of 60°N but south of the ice edge.

The SAR wind retrievals were averaged into 25 kilometer \times 25 kilometer areas to match the ASCAT lower-resolution scatterometer measurement. The mean difference between Sentinel-1A and ASCAT winds was -0.45 meters per second, with a standard deviation of 1.82 meters per second. These results are comparable to the validation results from Radarsat-2 (mean difference of -0.60 meters per second and standard deviation of 1.51 meters per second [Monaldo et al., 2013]). For details of the comparison, see Monaldo et al. [2015].

Once Sentinel-1A ramps up to full operations, we also intend to make direct Sentinel-1A and Radarsat-2 comparisons.

More Applications to Come

Now that NOAA has successfully created regular Radarsat-2 SAR Winds images that can be used by coastal managers, NOAA has plans to produce additional SAR-based products. These plans will be aided by the integration of the large volumes of SAR imagery expected from Sentinel-1 and the Canadian Radarsat Constellation Mission (2018).

Future products, now undergoing preliminary tests, are expected to include an automated sea ice masking and classification, ship detection, oil spill mapping, and ocean wave spectra. As each product is validated, it will be incorporated into routine dissemination systems. NOAA expects that the availability of free and open Sentinel-1 SAR imagery from ESA will greatly accelerate and expand the development of new applications of SAR.

Acknowledgments

This work is supported by the NOAA Product Development, Readiness and Application (PDRA)/Ocean Remote Sensing (ORS) Program. The views, opinions, and findings contained in this paper are those of the authors and should not be construed as an official NOAA or U.S. government posi-

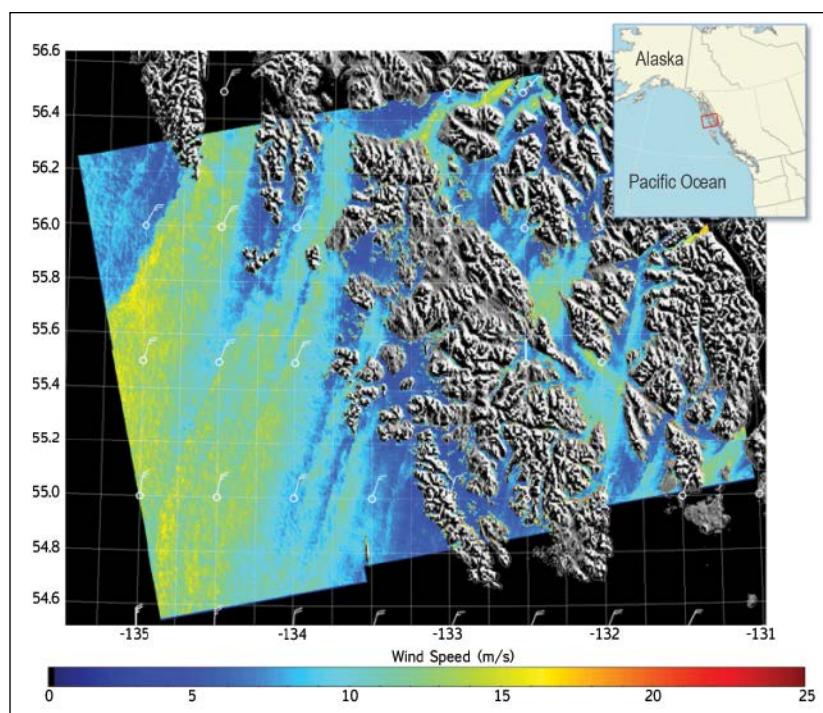


Fig. 1. Sentinel-1A synthetic aperture radar-derived wind speed image for data acquired on 28 November 2014 at 02:37:03 coordinated universal time off the coast of southeastern Alaska. The colors represent wind speed, and the gray area is a shaded-relief map over the land areas. The wind bars represent the wind vectors from the Global Forecast System (GFS) model at a 10-meter height above the surface.

tion, policy, or decision. The strong and continued support of the Alaska Weather Service and ice forecasters at the U.S. National Ice Center was key in making SAR Winds an operational NOAA product.

References

- Helfrich, S. R., D. McNamara, B. H. Ramsay, T. Baldwin, and T. Kasheta (2007), Enhancements to, and forthcoming developments in the Interactive Multisensor Snow and Ice Mapping System (IMS), *Hydrol. Processes*, 21, 1576–1586.
- Hersbach, H. (2010), Comparison of C-band scatterometer CMOD5.N equivalent neutral winds with ECMWF, *J. Atmos. Oceanic Technol.*, 27, 721–736, doi:10.1175/2009JTECH06981.
- Monaldo, F. M., V. Kerbaol, and the SAR Wind Team (2004), The SAR measurement of ocean surface winds: An overview, in *Proceedings of the Second Workshop on Coastal and Marine Applications of SAR*, Eur. Space Agency Spec. Publ., ESA SP-565, 15–32.
- Monaldo, F. M., C. R. Jackson, and W. G. Pichel (2013), Seasat to Radarsat-2: Research to operations, *Oceanography*, 26(2), 34–45.
- Monaldo, F. M., C. R. Jackson, W. G. Pichel, and X. Li (2015), Early validation of operational SAR wind retrievals from Sentinel-1A, paper presented at IEEE Geoscience and Remote Sensing Symposium, Inst. of Electric. and Electron. Eng., Milan, Italy, 26–31 July.
- Stoffelen, A. C. M., and D. L. T. Anderson (1997), ERS-1 scatterometer data characteristics and validation of the transfer function: CMOD4, *J. Geophys. Res.*, 102, 5767–5780.
- Weissman, D. E., D. King, and T. W. Thompson (1979), Relationship between hurricanes surface winds and L-band radar backscatter from the sea surface, *J. Appl. Meteorol.*, 18, 1023–1034.
- Wright, J. W. (1960), Backscattering from capillary wave with application to sea clutter, *IEEE Trans. Antennas Propag.*, 14, 749–754.

Author Information

F. M. Monaldo, Applied Physics Laboratory, National Oceanic and Atmospheric Administration (NOAA) and Johns Hopkins University, College Park, Md.; email: frank.monaldo@noaa.gov;
C. R. Jackson, Global Science and Technology (GST), NOAA, College Park, Md.;
W. G. Pichel, NOAA, College Park, Md., retired; and
X. Li, GST, NOAA, College Park, Md.

Prioritizing Development



©iStock.com/Newbird

Earlier this year, at the invitation of AGU president Margaret Leinen, I accepted the position of chair of the new AGU Development Board. I was confident that this would provide an excellent opportunity to give back to AGU and help it continue to be the leading organization of the Earth and space sciences.

AGU relies heavily on member volunteers to carry out its mission. The financial generosity of our donors makes many of AGU's programs possible, in turn generating additional value for our members.

This year, AGU has revitalized its approach to development.

New Development Board

This year, AGU has revitalized its approach to development, hiring a new development director and reestablishing its Development Board after a period without one. I am pleased to recognize the 13 members who have agreed to join me on the new board:

- Mike McPhaden (vice chair), National Oceanic and Atmospheric Administration
- Sunanda Basu, National Science Foundation
- James Burch, Southwest Research Institute
- John Delaney, University of Washington

- Donald Dingwell, Ludwig Maximilian University of Munich
- John Geissman, University of Texas at Dallas
- Cynthia Greeley, Arizona State University
- Timothy Grove, Massachusetts Institute of Technology
- William Reeburgh, emeritus, University of California, Irvine
- Joaquin Ruiz, University of Arizona
- Peter Schlosser, Columbia University
- Kiyoshi Suyehiro, Japan Agency for Marine–Earth Science and Technology
- Bruce Tsurutani, NASA Jet Propulsion Laboratory

The Development Board met for the first time in mid-June. We look forward to making development an organizational priority by increasing engagement with all current and potential contributors.

Thanking Donors

As a member of AGU for nearly 40 years, I have been impressed by its growth and the wide-ranging impact of its meetings and journals. AGU has made a significant impact on Earth and space scientists and our sciences for several generations.

AGU's leaders appreciate all members who financially contribute to the organization—from donors with more than \$10,000 in lifetime giving to students and early-career scientists who made their first contributions last year. Thank you all for your tremendous support of AGU.

Yet one of the most staggering statistics shared with Development Board members

during the June meeting is that only 7% of AGU members financially contribute to AGU, at any level. Fewer than 4500 of our 60,000+ members donated to AGU in 2014.

Goal to Increase Donor Rolls

At its initial meeting, the new Development Board set a challenge goal: increase the rate of participation from AGU members to 12% in 2015. This will require an additional 3000 members to make financial contributions to AGU. I truly believe that once everyone understands the impact of their giving and the increased number of programs, scholarships, grants, etc., that AGU can provide with these additional revenues, we will see a significant increase in AGU member donors in 2015.

AGU has made development a priority, and now I am asking all members to do the same. If you have benefited from being an AGU member, as I have, give back. Or if you are a new member and wish to see our Union thrive for generations to come, pay forward.

Questions Are Welcome

My fellow Development Board members and I are happy to answer any questions you may have regarding AGU's fundraising efforts. For more information, contact Jeff Borchardt, AGU director of development, at jborchardt@agu.org. To make a contribution to an AGU fund of your choice or to view the list of AGU donors who have given \$50 or more to date in 2015, please visit <http://giving.agu.org>.

By **Carlos Dengo**, Chair, AGU Development Board

2014 AGU Donor Snapshot

- 4368 out of 60,000 members (7%) made donations
- 37 donors made contributions of \$1000 or more
- 795 donors made contributions of \$100 or more (only 18% of 2014 donor base)
- 3016 donors made contributions of less than \$50 (69% of 2014 donor base)

Thank You to Our 2015 Individual Leadership Donors*

The leadership of AGU would like to thank all individuals that have made contributions of \$250 or more to AGU in 2015. Without your support many of AGU's scholarships, grants, and other programs wouldn't be possible.

Principal Society \$25,000+ Annually

Sunanda Basu
Cynthia Greeley
Integrated Ocean Drilling
Program Management
International

President's Circle \$1,000+ Annually

John J. Bates
Robin E. Bell
Jeff Borchardt
James L. Burch
Eric A. Davidson
Carlos A. Dengo
John W. Geissman
Kristine Harper
Elizabeth A. E. Johnson
Elizabeth F. Karplus
Frank Krause
Margaret Leinen
Kathleen Mandt
David J. McComas
Hazelyn and Harrold McComas
Charitable Trust
Christine McEntee
Michael J. McPhaden
Mark Moldwin

Louise Pellerin
William S. Reeburgh
Dana Rehm
Alan Robock
Kiyoshi Suyehiro
Ultimate Software Group

Leadership Circle \$500+ Annually

Thomas P. Ackerman
Rafael L. Bras
Hugh J. A. Chivers
Millard F. Coffin
Martha H. Conklin
Cygnnet Strategy, LLC
John S. Dickey, Jr.
Russell C. Evarts
Rana A. Fine
Efi Foufoula-Georgiou
Thomas E. Graedel
Robert T. Gregory
Shin-Chan Han
Brooks Hanson
Krista Geralyn Herbstrith
Seth Kahan
Dennis P. Lettenmaier
Zhanqing Li
Charles Luce

Richard H. Picard
Richard B. Rood
Stephen Self
Edward C. Stone
David J. Thomson
Thomas A. Weaver

Prow Partners \$250+ Annually

Mary P. Anderson
Hans G. Ave Lallemand
Harvey E. Belkin
Karen G. Bemis
Vickie C. Bennett
Scott A. Budzien
James A. Coakley, Jr.
Delia Donatelli
Jeff Dozier
Larry W. Esposito
Donald W. Forsyth
Lawrence J. Giles
Hans C. Graber
Martin Heimann
Margaret Hellweg
Amanda R. Hendrix
Dana Hurley
Eric Itsweire
Angela S. Jayko

Stephen W. Kahler
Miriam Kastner
Max A. Kohler
Alan Levander
Kuo-Nan Liou
Barry Mauk
Judith A. McKenzie
Jason S. McLachlan
Stephen B. Mende
Robert L. Molinari
Marcia Neugebauer
Anne Walden Nolin
John Pitlick
Robert E. Reinke
Roberta L. Rice
Kim Richardson
Fred L. Roesler
Katherine Skalak
R. Stephen J. Sparks
Elena B. Sparrow
Anahita Ani Tikku
Adam D. Trombly
Mark Vaughan
Peter J. Webster
Ray F. Weiss
Rodney W. Whitaker
Adam H. Winstral

To make a contribution to AGU, please visit the website at giving.agu.org or contact Claire Howard, Development Coordinator, at choward@agu.org or (202) 777-7434.



A Guide to Writing an AGU Abstract

To give a talk or poster at an AGU conference, you have to write an abstract. Putting together a well-composed abstract can feel daunting after making it through the task of the research itself. Although you know everything needed to understand your research, how do you sum that up for someone else? And how much information should you include?

It may seem overwhelming at first, but the process can be broken down into several simple steps. Keep in mind that an abstract is not merely a summary; it is a presentation of your research findings. Think of it as writing a very condensed scientific paper.

Step 1: Choose a Meeting

AGU meetings offer a wealth of opportunities for you to share your research (see <http://meetings.agu.org>). When choosing a conference, make sure to plan in advance; abstract submission deadlines generally fall several months before the event is held.

The annual Fall Meeting in December offers the most recognized AGU opportunity, but its abstract submission deadline for this year has passed. You can turn to other AGU-sponsored meetings, such as the Ocean Sciences Meeting in February 2016 and smaller, more specialized meetings known as Chapman conferences (<http://chapman.agu.org/>).

AGU meetings offer a number of opportunities specifically for students. These include an undergraduate poster session at the Fall Meeting, especially useful for first timers who would prefer to present in front of their peers rather than in discipline sessions. Additionally, students who wish to present at AGU meetings but need help with costs can apply for travel grants (see <http://education.agu.org/grants/>).

Also, specifically for students, the Virtual Poster Showcase offers online sessions in October and November for student presenters and their faculty coauthors in the Earth, atmospheric, ocean, space, and environmental sciences (see <http://bit.ly/VirtPoster>).

Because it is virtual, the showcase allows students to share their research from anywhere, making it a great option for students who can't afford to travel to present their findings. Abstract submissions open 28 September for Virtual Poster Showcase #2 (for

undergraduate students) and Virtual Poster Showcase #3 (for graduate students). Abstract submissions for Virtual Poster Showcase #1 closed a few days ago.

Step 2: Read Other AGU Meeting Abstracts

Before you begin writing, you can get a better idea of how to craft your abstract by perusing abstracts that others have written. AGU's website provides access to tens of thousands of such abstracts from past AGU meetings (see <http://bit.ly/PastAbstracts>). The more you become familiar with the literature of abstracts, the easier it will be when you sit down to write your own.



Each of the tens of thousands of posters and oral talks presented at AGU meetings every year requires an abstract.

Step 3: Review AGU's Guidelines

No matter what AGU meeting or conference you plan to attend (including the Virtual Poster Showcase), you must limit your abstract to 2000 characters, including spacing and punctuation. Likewise, your abstract title must fit within the span of 5 to 300 characters. AGU welcomes submission with your abstract of no more than one graph or other image (JPEG, PNG, or GIF only).

AGU identifies whoever submits an abstract as its first author. Other authors, including advisers or professors, field or laboratory assistants, and members of the research team, can be added later.

Depending on the conference or meeting, AGU may require the first author to be a current member whose dues are paid for that year. Check specific conference guidelines to see if the first author must be an AGU member.

Step 4: Begin Writing

As you write your abstract, break it down into different components. Think of the abstract-making task as writing a very brief peer-reviewed paper. It should include the following:

- **Context/Purpose:** One to two sentences explaining why you studied this particular topic and what is significant about it. Has past research been done? How does your research add to existing knowledge?
- **Methods:** One to two sentences outlining the methods you used to conduct your research. How did you collect your data? How did you process your data?
- **Results:** Three to four sentences about what you found through your research.
- **Interpretation:** Up to four sentences discussing those findings. What do the results mean?
- **Conclusion:** One sentence summarizing what you have learned from your research and why it is significant.

Step 5: Submit!

When you submit your abstract, choose the specific session that is most applicable to your research.

Most meetings have abstract submission fees that help cover the cost of the meeting or virtual poster session. Expect to pay about \$65.00 for a regular submission and \$35.00 for a student submission. AGU waives abstract fees for submitters from developing countries.

Step 6: Enjoy the Rewards

Presenting your research to your professional peers provides a unique opportunity to practice communicating science. Creating a presentation and sharing your findings helps you hone skills needed to convey technical material effectively. Meetings also allow you to network with other scientists in the field and gain insight into the latest scientific findings. You've worked hard to conduct your research; now go share it with the scientific community!

This article was largely influenced by "How to write an abstract for a Geological Society of America conference" by Dan Deo-campo (http://bit.ly/GSA_abstract).

By **Victoria Anania**, AGU Education Intern; email: vanania@agu.org

Lightning “Impulses” Improve Models of Global Electrical Circuit



John Fowler, CC BY 2.0 (<http://bit.ly/ccby2-0>)

Lightning strikes the New Mexican desert. The electric potential in thunderstorms powers the global electrical circuit—a system of flowing currents that encircles the planet and extends into space.

Earth’s biggest electrical circuit can be found in its atmosphere, where currents flow between the ground and the ionosphere. This global electrical circuit (GEC) gets power from thunderstorms pumping positive charge into the ionosphere—the electrically charged layer of the Earth’s upper atmosphere. This charge gradually returns to the ground during fair weather.

Now Jánský and Pasko have introduced a new model to simulate this process in greater detail while also improving the speed of the simulations with a few mathematical tricks. They use a spherical coordinate system, in which locations are defined using angles from an axis or on a plane—like latitude and longitude. Previous simulations used a coordinate system that treated thunderstorms like cylinders or introduced several constraints on electric potential. Spherical coordinates allow the team to calculate the electric potential in the system directly from first principles, making the new model more precise.

Another innovation involves a technique called impulse response. Consider an acoustical analogy: applying a realistic reverberation effect to make a musical recording sound as if the players were in a spacious concert hall. Instead of calculating the physics of every note bouncing around the auditorium, technicians make a sample recording of a single

sound. A crack of a snare drum reverberates through the hall, capturing its characteristic echoes—an impulse response. Audio engineers digitally meld the waveform of that impulse with a recording of an entire musical performance, mathematically applying the reverberation to every note to make an entire orchestra sound as if it’s playing in a concert hall without using much computational power.

The authors apply this concept to modeling thunderstorms and the GEC. By precalculating the overall effect of a single charge introduced in their simulations, they create impulse responses that they use to efficiently calculate the response of the entire system to changes in current and their impact on the GEC.

They report that this model captures the behavior of electrical currents in a thundercloud, including how the movement of charges within the cloud creates an imbalance, and the instantaneous burst of electric potential that a cloud-to-ground lightning bolt injects into the ionosphere. They conclude that such lightning strikes are responsible for about 4% of the total ionospheric potential in the GEC, which is in line with previous studies—a further vote of confidence for their new approach. (*Journal of Geophysical Research: Space Physics*, doi:10.1002/2014JA020326, 2014) —Mark Zastrow, Freelance Writer

Airborne Sensor Can Track Photosynthesis Efficiency

Photosynthesis—the process by which plants use sunlight to convert carbon dioxide and water into carbohydrates—is the basis of nearly all energy available for life on Earth. Understanding how plants regulate short-term changes in photosynthesis in response to varying environmental conditions is important for improving plant production and for coping with climate change.

When photosynthesis efficiency falters, a portion of the sunlight not absorbed by a plant will be emitted in the form of chlorophyll fluorescence. In a new study, *Rossini et al.* used a new airborne imaging spectrometer to map this fluorescence signal.

Plants generally use the majority of the light they absorb for photosynthesis; only a small part is emitted as chlorophyll fluorescence or as heat. However, under suboptimal growing conditions, plants reduce their photosynthetic efficiency. Because the fate of any light striking a plant will be involved in either photosynthesis, fluorescence, or heat dissipation, any variation in the efficiency of one process affects the efficiencies of the others.

Under this logic, the researchers reasoned they could infer photosynthetic efficiency by measuring the chlorophyll fluorescence emission. To measure the chlorophyll fluorescence, the team studied vegetation treated with an herbicide that interrupts electron transport during photosynthesis and also inhibits heat dissipation.

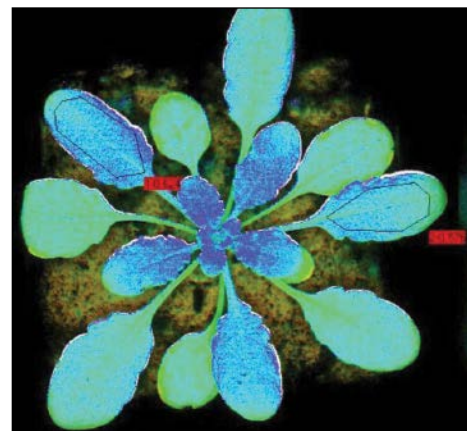
Whereas previous studies have reported the use of tower platforms to accurately measure chlorophyll fluorescence in the far-red spectral region, it has been more difficult to measure the red signal because of the insufficient resolution of available sensors. To overcome this limitation, *Rossini* and her team employed a spectrometer that will be launched on the European Space Agency's Fluorescence Explorer (FLEX) satellite mission. The heart of this spectrometer is the Hyplant sensor—the only currently available aerial sensor with a subnanometer spectral resolution in the red to far-red spectral region.

From an airborne platform, the researchers used Hyplant and measured a significant increase of both red and far-red fluorescence on a

grass field that had been sprayed with the herbicide. Fluorescence increased at higher herbicide concentrations, whereas no changes in fluorescence were observed on an untreated control field.

These observations prove the feasibility of estimating chlorophyll fluorescence in the far-red and, for the first time, the red spectral regions from an airborne platform and demonstrate that both of these signals can be used to infer changes in the photosynthesis efficiency.

The herbicide applied in this study induces an increase of fluorescence emission because it blocks the two pathways occurring in competition with fluorescence: photosynthesis and nonradiative dissipation as heat. In contrast, other stressors tend to induce a reduction of photosynthetic efficiency but typically increase nonradiative dissipation, which generally results in a decline in fluorescence emission. Thus, the authors note that the pathway by which factors influence photosynthesis is important to understand. (*Geophysical Research Letters*, doi:10.1002/2014GL062943, 2015) —Chris Palmer, Freelance Writer



Chlorophyll fluorescence emitted from the core of a plant's photosynthetic machinery after absorption of light, as imaged in a laboratory. Fluorescence reflects vegetation health: Generally, the greener the leaf is, the higher the fluorescence emission is and the healthier the leaf is. However, herbicides that inhibit heat dissipation as well as photosynthesis can also induce an increase of fluorescence.

Shizue Matsubara, Forschungszentrum Jülich

New Models Explain Unexpected Magnitude of China's Wenchuan Quake

On 12 May 2008, a magnitude 7.9 earthquake struck China's Sichuan Province, causing approximately 70,000 deaths and leaving more than 18,000 people missing.

The quake, named for its epicenter in Wenchuan County, occurred around 2:30 p.m. local time and was, in many ways, a surprise to scientists studying the region's geology. GPS data obtained from the area before the Wenchuan event gave no indication that so much energy was building up below Earth's surface. Since the catastrophe occurred, scientists have been collecting more data and rethinking the physics of the region.

Earth scientists often attempt to record GPS data from Earth's surface to infer how much activity is occurring below. As tectonic plates slide and grind against each other, they scrunch Earth's surface into mountain ranges and other geological features. A suitably sensitive GPS system can track this deformation; scientists can then use these data to calculate crustal shortening—an

important indicator of earthquake potential that measures how much overlap and folding is occurring in Earth's crust. Prior to the Wenchuan event, shortening was thought to be near zero in the region, but the occurrence of such an enormous quake suggested otherwise.

Now *Thompson et al.* have created expanded mathematical models, which include new variables like earthquake cycle and topographic effects. They concluded that the shortening rate in the region is closer to 5.7 ± 1.5 millimeters per year or more.

Another important addition to the model is the inclusion of a detachment fault 20 kilometers below Earth's surface. Not only do the new models predict the buildup of elastic energy in Earth's crust, they also indicate that earthquakes such as Wenchuan's may be more common than previously thought—occurring as often as once every 600 years. (*Geophysical Research Letters*, doi:10.1002/2014GL062833, 2015) —David Shultz, Freelance Writer

Ice-Penetrating Radar Reveals Age of Greenland Ice Sheet Layers

Although the Greenland Ice Sheet has been surveyed extensively since the 1960s using ice-penetrating radar, efforts to map the ice sheet's internal structure directly have been limited. This is because tracing the internal reflections observed by radar—"layers" that indicate changes in ice composition—is labor intensive and difficult in areas of complex ice flow. Consequently, despite the valuable insights into ice sheet dynamics provided by such surveys, numerous data sets currently exist for which few or no internal reflections have been mapped or interpreted.

To harness these data, a team of researchers has developed new methods to semiautomatically trace and verify these layers and date them. By combining these results with established methods, MacGregor *et al.* have produced the first comprehensive radiostratigraphy of the Greenland Ice Sheet, opening the door for new insights into the ice sheet's internal dynamics as well as its millennial-scale response to oceanographic, atmospheric, and subglacial forcings.

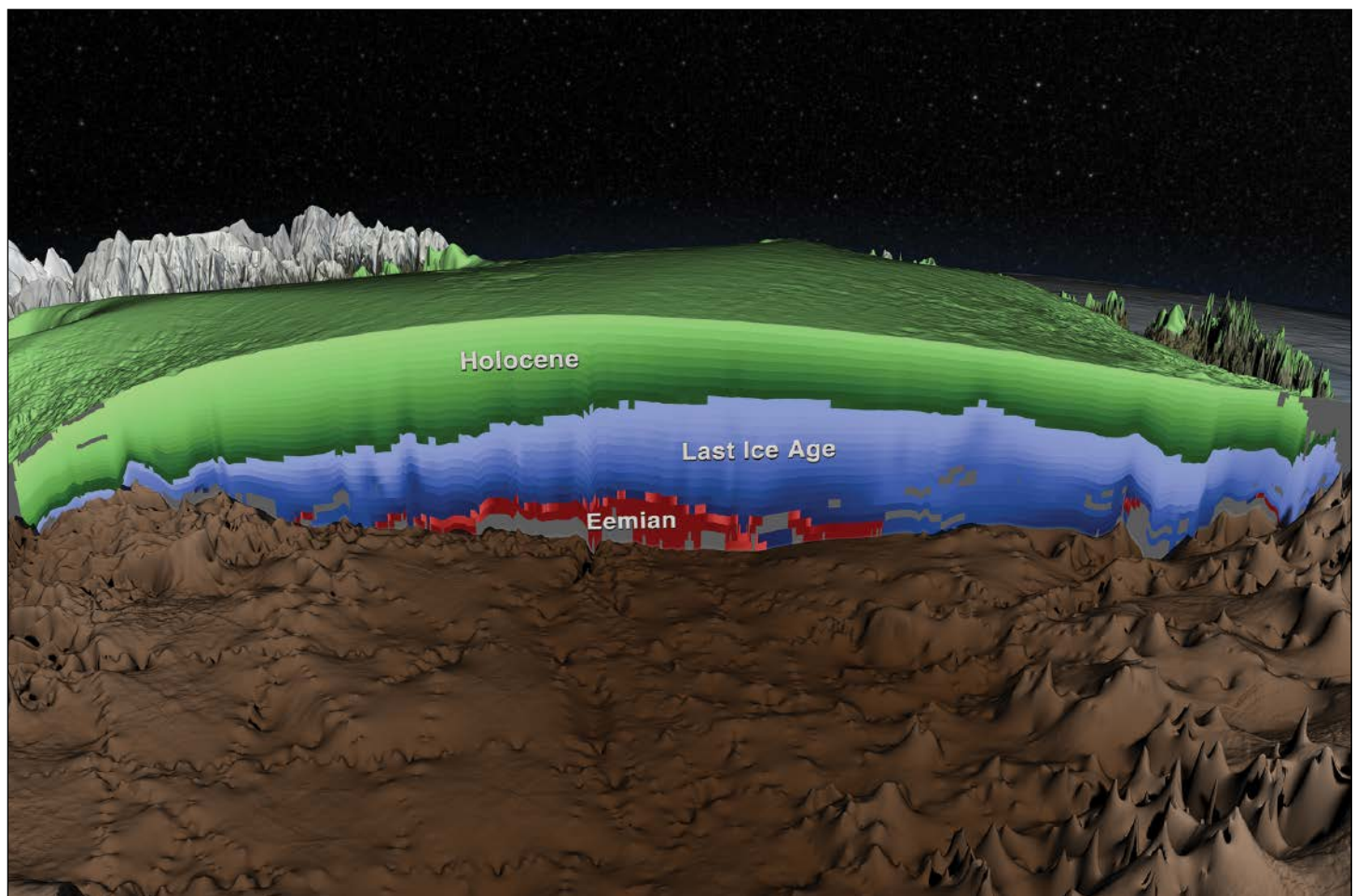
By analyzing nearly 480,000 kilometers of deep ice-penetrating radar data collected by the University of Kansas between 1993 and 2013, the researchers show that the ice sheet's essential age structure is monotonous across large sectors, particularly within its upper lay-

ers. The base of the ice sheet, however, hosts numerous complex features and disrupted ice in several regions where ice begins to flow more quickly. Disrupted ice may also indicate where ice flow has changed suddenly in the past.

Using the oldest identified reflections, the researchers conclude that several areas in the ice sheet's northern interior could hold undisturbed ice from the Eemian—the most recent interglacial period that lasted from about 130,000 to about 115,000 years ago—near the ice sheet's bed.

A video developed by NASA's Scientific Visualization Studio uses three-dimensional animations to show exactly where Eemian ice can be found within the Greenland Ice Sheet (see http://bit.ly/3-D_ice layers). The team notes that these locations should be further evaluated as potential deep ice core sites.

The researchers argue that large-scale ice flow models should incorporate these new data so that they can better reproduce both the modern state of the Greenland Ice Sheet and its history, which likely contains clues to its future response to ongoing climate change. (*Journal of Geophysical Research: Earth Surface*, doi:10.1002/2014JF003215, 2015) —Terri Cook, Freelance Writer



The first comprehensive analysis of ice-penetrating radar data revealed the ages of the layers in the Greenland Ice Sheet.

virtual poster showcase

Students Can Now Share Their Research—From Anywhere!

This is a new opportunity that allows undergraduate and graduate students to present their research virtually, without any need to travel.

Advantages of Virtual Presentations Over In-person Meetings



Less Time



Lower Cost



More Flexible Scheduling

Students

- **Share** your research
- **Practice** your presentation skills
- **Review** the posters of your peers
- **Receive** quality feedback from peers and experts in your field
- **Build** your credibility

Faculty

- **Help students** develop their presentation skills and ability to evaluate science
- **Impact more students** with the funds you have
- **Incorporate Virtual Poster Showcases** in a capstone course

Sign up to receive e-mail alerts about upcoming Virtual Poster Showcases

virtualposter.agu.org

3 Opportunities to Participate in Fall 2015

Virtual Poster Showcase #1

For Undergraduate Students

Virtual Poster Showcase #2

For Undergraduate Students

Virtual Poster Showcase #3

For Graduate Students

Join the conversation



@theAGU
#VirtualPoster



AGU's Career Center is the main resource for recruitment advertising.

All Positions Available and additional job postings can be viewed at Eos.org at <https://eos.org/jobs-support>.

AGU offers printed recruitment advertising in *Eos* to reinforce your online job visibility and your brand.

Contact advertising@agu.org for more information about reserving an online job posting with a printed *Eos* recruitment advertisement.

LINE LISTING RATES:

- > \$0.32 per character for first issue of publication
- > \$0.26 per character for each additional issue of publication

STUDENT OPPORTUNITY RATES:

- > No Cost up to 500 characters
- > \$0.16 per character over 500 characters for first issue of publication
- > \$0.16 per character for each additional issue of publication

EMPLOYMENT DISPLAY ADVERTISING RATES (OPEN RATE, BLACK AND WHITE):

- > Full Page : \$5,500.00 net
- > Half Page: \$2,160.00 net
- > Third Page: \$1,450.00 net
- > Quarter Page: \$1,090.00 net
- > Sixth Page: \$730.00 net
- > Eighth Page: \$590.00 net
- > To view all employment display ad rates, visit <http://sites.agu.org/media-kitsfiles/2014/12/Eos-Employment-Advertising.pdf>

COLOR RATES:

- > One Color: \$315.00 net
- > Full Color: \$980.00 net

- > *Eos* is published semi-monthly on the 1st and 15th of every month.

Deadlines for ads in each issue are published at

<http://sites.agu.org/media-kits/eos-advertising-deadlines/>.

- > *Eos* accepts employment and open position advertisements from governments, individuals, organizations, and academic institutions. We reserve the right to accept or reject ads at our discretion.
- > *Eos* is not responsible for typographical errors.
- > Print only recruitment ads will only be allowed for those whose requirements include that positions must be advertised in a printed/paper medium.

Atmospheric Sciences

Associate Professional Specialist/ Professional Specialist Position in Intraseasonal-to-Decadal Real-time Predictions and Predictability Research

In collaboration with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), the Atmospheric and Oceanic Sciences Program at Princeton University is seeking candidates with a strong computational and technical background to fill an associate professional specialist/professional specialist position.

Candidates will join a vibrant research team and play a leading role in supporting real-time seasonal forecasting of climate using complex models simulating the Earth system. The position will require performing predictions every month, as well as research into predictability. This will involve configuration, running and analysis of state-of-the-art coupled climate models running on supercomputers.

Initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding. Some amount of travel (to conferences or workshops) may be required. Salary commensurate with experience.

Complete applications, including a CV, copies of recent publications, names and contact information for at least 3 references are required in order to solicit letters of recommendation; applications should be submitted by October 15, 2015 for full consideration. Applicants should apply online to <http://jobs.princeton.edu>, Requisition #1500566. For additional information, contact Gabriel Vecchi (gabriel.a.vecchi@noaa.gov).

This position is subject to the University's background check policy. Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Postdoctoral Scientist in "Multi-Decadal Internal Climate Variability and Its Role in Climate Change"

The Atmospheric and Oceanic Sciences Program at Princeton University, in cooperation with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a postdoctoral scientist for research related to multi-decadal internal (natural) climate variability and its potential role in explaining observed climate changes. A key focus is to improve understanding of the role of low frequency internal climate variability in the current "hiatus" in global warming, as well as previous hiatus and accelerated-warming periods during the 20th century. Such under-

standing plays an important role in the detection and attribution of observed climate changes. The research will use various approaches to understand the physical mechanisms causing the observed decadal changes including quantification of contributions from both internal climate variability and responses of the climate system to various natural and anthropogenic forcing agents (e.g., greenhouse gases, aerosols, and volcanic eruptions). The research will make extensive use of both observations and a variety of modeling tools. The selected candidate will have a Ph.D. and one or more of the following attributes: (a) a strong background in climate/ocean dynamics or coupled air-sea interactions, (b) experience conducting and analyzing coupled climate model experiments, and (c) strong diagnostic skills in analyzing simulated and observed data sets.

This is a two-year position (subject to renewal after the first year contingent upon satisfactory performance and funding availability) based at GFDL/NOAA in Princeton, New Jersey. Complete applications, including a CV, publication list, names of 3 references for letters of recommendation, and a one-to-two page statement of research interests should be submitted. Review of applications will begin as soon as they are received and continue until the position is filled. Applicants should apply online to <http://jobs.princeton.edu>.

edu, Requisition #1500509. For additional information on the position, please contact Rong Zhang (Rong.Zhang@noaa.gov) or Tom Knutson (Tom.Knutson@noaa.gov). This position is subject to the University's background check policy.

Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, disability status, protected veteran status, or any other characteristic protected by law.

Hydrology

Geoscience and Water Sustainability – Tenure-track Position

The Department of Geology and Environmental Science at the University of Pittsburgh (<http://www.geology.pitt.edu>) invites applications for a tenure-track assistant professor position in geoscience and water sustainability, pending budgetary approval. We seek applicants to expand our current research in sustainability and who link field-based geoscience research to quantitative sustainability themes. Areas of expertise may include, but are not limited to: catchment hydrology in urban, managed, and natural systems; land-atmosphere interactions; soil moisture analysis; the interacting roles of climate variability and land use change on hydrologic processes; or

physical models of ecohydrologic and hydrogeologic processes from the plot to the global scale. The successful candidate will complement existing research clusters and establish an externally-funded, internationally recognized research program.

Review of applicants will begin on October 15, 2015 and continue until the position is filled. A PhD is required at the time of appointment, with an anticipated start date in Fall 2016. Please apply online to: <https://facultysearch.as.pitt.edu/apply/index/OTY>. Applications should include: 1) a cover letter; 2) a CV; 3) statements of research and teaching interests; 4) names and contact information of four references; and 5) copies of three relevant publications. Direct questions to the Search Committee Chair, Dr. Daniel Bain, dbain@pitt.edu, 412-624-8766. The University of Pittsburgh is an Affirmative Action/Equal Opportunity Employer and values equality of opportunity, human dignity and diversity.

Tenure-Track Assistant Professor Position GROUNDWATER HYDROLOGIST University of Wyoming

The Department of Civil and Architectural Engineering at the University of Wyoming invites applications for a tenure-track faculty position in Groundwater Hydrology at the Assistant Professor level. We seek a candidate with the interest and ability to develop and sustain a nationally competitive research program. The successful candidate must hold an earned doctoral degree in Civil Engineering or in a closely related discipline by the position start date. Registration as a professional engineer or professional hydrologist are desirable but not required. The successful candidate must be able to teach courses in fluid mechanics, hydraulics, hydrology, and water resources engineering. Also, the successful candidate must have the demonstrated ability to develop an externally funded research program in groundwater hydrology.

This position will become part of a major research thrust in water resources at the University of Wyoming. Groundwater resources are of immense importance to societal and ecological needs. Approximately half of Wyoming water resources are from groundwater, and subsurface resources provide critical water to agriculture, oil and gas development, and municipalities. There are tremendous research challenges in groundwater resulting from changing climate signals and human population patterns, and emerging techniques provide outstanding opportunities for groundwater hydrologists to better quantify the fate and transport of water in a changing west. We seek a groundwater hydrologist with experience in laboratory and field approaches for describing complex subsurface processes. Areas of specific interest include, but are not limited to, surface-groundwater

interaction, unsaturated flow and contaminant transport.

As a member of the faculty of the Department of Civil and Architectural Engineering, the successful candidate will integrate his or her research with the goals of the new Wyoming Center for Environmental Hydrology and Geophysics (<http://www.uwyo.edu/epscor/wycheh/>) and provide academic support to the PhD program in Water Resources, Environmental Science and Engineering (<http://www.uwyo.edu/wrese/>).

UW faculty have access to world-class computational resources as described at: <https://arcc.uwyo.edu/>. The department is supported by 22 tenured or tenure-track faculty and offers ABET-accredited baccalaureate programs in both civil engineering and architectural engineering to approximately 300 undergraduate students. The department also offers graduate programs at the Masters and PhD levels to roughly 60 graduate students.

Laramie is a picturesque and friendly town offering a reasonable cost of living, good K-12 public schools and easy access to outdoor activities in the Rocky Mountain region. Additional information on the Department, College, and Laramie is available at: <http://www.uwyo.edu/civil>, <http://ceas.uwyo.edu> and <http://www.laramie.org>.

Applications must include: 1) a letter of application, 2) a curriculum vitae including a list of publications, 3) a statement of research interests, 4) a statement of teaching interests, and 5) contact information for at least three references. Do not include supplemental information such as off-prints of papers, reference letters, or transcripts. Review of applications will begin 15 September 2015 and continue until the position is filled. The preferred start date for the position is January 2016. Submit applications in a single PDF file to: water_search@uwyo.edu.

The University of Wyoming is an Equal Employment Opportunity/Affirmative Action employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, disability or protected veteran status or any other characteristic protected by law and University policy. Please see: <http://www.uwyo.edu/diversity/fairness>. We conduct background investigations for all final candidates being considered for employment. Offers of employment are contingent upon the completion of the background check.

Ocean Sciences

Department of Marine, Earth, and Atmospheric Sciences Assistant Professor – Marine Microbiology

The Department of Marine, Earth, and Atmospheric Sciences (MEAS) at North Carolina State University (NC State) is seeking to fill a tenure-track faculty position at the Assistant Pro-

POSTDOCTORAL RESEARCH AND VISITING RESEARCH SCIENTISTS ATMOSPHERIC AND OCEANIC SCIENCES PRINCETON UNIVERSITY/GFDL

In collaboration with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), the Atmospheric and Oceanic Sciences Program at Princeton University solicits applications to its Postdoctoral and Visiting Research Scientist Program.

The AOS Program and GFDL offer a stimulating environment with significant computational and intellectual resources in which to conduct collaborative or independent research. We primarily seek applications from recent Ph.D.s for postdoctoral positions but will accept applications from more experienced researchers. Applications from independent researchers and more senior scientists who may need partial support for sabbatical or short visits may also be considered. Postdoctoral appointments are initially for one year with the possibility of renewal for a second year based on satisfactory performance and continued funding. A competitive salary is offered commensurate with experience and qualifications. We seek applications in all areas of the climate sciences. This includes research in basic processes in atmospheric and oceanic dynamics; climate dynamics, variability and prediction; atmospheric physics and chemistry; cloud dynamics and convection; boundary layer processes; land-sea-ice dynamics; continental hydrology and land processes; physical oceanography; ocean-atmosphere interaction; climate diagnostics and analysis. Applicants must have a Ph.D. in a relevant discipline by the time their appointment starts.

Further information about the Program may be obtained from: <http://www.princeton.edu/aos/>. Applicants are strongly encouraged to contact potential hosts at GFDL and Princeton University prior to application to discuss areas of possible research.

Complete applications, including a CV, copies of recent publications, at least 3 letters of recommendation, and a titled research proposal should be submitted by September 30, 2015 for full consideration. Applicants should apply online to <http://jobs.princeton.edu>, Requisition #1500632. These positions are subject to the University's background check policy. Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law.

ETH zürich

Assistant Professor (Tenure Track) of Glaciology

→ The Department of Civil, Environmental and Geomatic Engineering (www.baug.ethz.ch) at ETH Zurich and the Swiss Federal Institute for Forest, Snow and Landscape Research, WSL (www.wsl.ch) invite applications for the above-mentioned assistant professorship.

→ The assistant professor will lead a research group to be shared between the Department of Civil, Environmental and Geomatic Engineering at ETH Zurich and the Swiss Federal Institute for Forest, Snow and Landscape Research, with a strong research focus on alpine glaciology. The new assistant professor will be expected to teach undergraduate and graduate level courses, to maintain an active research programme, and to contribute to the departmental service. The research group will be located at the Laboratory of Hydraulics, Hydrology and Glaciology at ETH campus Hönggerberg in Zurich as well as at the Swiss Federal Institute for Forest, Snow and Landscape Research in Birmensdorf.

→ The successful candidate should hold a doctoral degree in civil or environmental engineering or a related discipline and should have expertise in physical glaciology. Relevant research areas include, but are not limited to, dynamic behavior of mountain glaciers, sub-glacial processes, fracture growth and mechanical failure in glacier ice, glacier hazards and climate-glacier interactions. We are particularly interested in individuals who combine acquisition and interpretation of data with theoretical work. The development and use of numerical models (e.g. ice flow, ice fracturing, glacier hydraulics) to combine research and engineering problems with observations is also a desired research direction. The selected candidate should establish an attractive teaching programme and must be committed to excellence in education, as well as promote, execute and apply modern teaching methods.

→ The new assistant professor will be expected to teach undergraduate level courses (German or English) and graduate level courses (English).

→ This assistant professorship has been established to promote the careers of younger scientists. The initial appointment is for four years with the possibility of renewal for an additional three-year period and promotion to a permanent position.

→ Please apply online at www.facultyaffairs.ethz.ch

→ Applications should include a curriculum vitae, a list of publications, and a statement of future research and teaching interests. The letter of application should be addressed to the President of ETH Zurich, Prof. Dr. Lino Guzzella. The closing date for applications is 30 September 2015. ETH Zurich is an equal opportunity and family friendly employer, and is further responsive to the needs of dual career couples. We specifically encourage women to apply.

fessor level in the area of marine microbiology. Expertise is desired in prokaryote ecology and molecular diversity with interests in genetic and biogeochemical methods for examining community composition and function in marine systems. Possible associated research areas include: biogeochemical-based ecosystem modeling; climate change; elemental cycling; extreme environments; food safety/security/public health; or water quality. A research focus on experimental and field studies using state-of-the-art molecular techniques is preferred, as are experience and a strong interest in interdisciplinary collaborations across and beyond the geosciences.

The position is available 1 August 2016. Applicants must hold a Ph.D. degree in the oceanographic or related sciences. The successful candidate must demonstrate strong potential for outstanding accomplishments in research, research supervision, and teaching. Specific course offerings may include undergraduate or graduate biological oceanography or marine microbiology, or other classes commensurate with the candidate's interest and expertise. An interest in participating in the Department's capstone undergraduate coastal processes field course also is desirable. MEAS places a high value on excellent instruction and the use of innovative teaching methods.

Located within the College of Sciences at NC State, MEAS is one of the largest interdisciplinary geoscience departments in the nation. Opportunities exist for disciplinary and interdisciplinary interactions with more than 30 marine, earth and atmospheric scientists. MEAS is one of six departments across three colleges with a presence at the NC State Center for Marine Sciences and Technology (CMAST), a coastal and marine science research facility located on Bogue Sound in Morehead City, NC. Additional information about the department and its facilities can be found on the web page: <http://www.meas.ncsu.edu> and <http://www.cmast.ncsu.edu>. NC State also hosts large programs in microbiology and biotechnology: <http://www.microbiology.ncsu.edu/> & <http://biotech.ncsu.edu/> and has recently established the Center for Geospatial Analytics: <http://geospatial.ncsu.edu>.

Review of applications will begin on 10 October 2015; the position will remain open until filled. Applications, including cover letters, curriculum vitae, teaching and research statements, and contact information for three references must be submitted online at <https://jobs.ncsu.edu/postings/56255>.

Founded in 1887, NC State is a land-grant institution distinguished by its exceptional quality of research, teaching, extension, and public service.



ROSENSTIEL AWARD

The Department of Marine Biology and Ecology at the University of Miami seeks nominations for the Rosenstiel Award. This award was created by the Rosenstiel Foundation to recognize outstanding contributions to marine science including oceanographically relevant aspects of atmospheric science and fundamental developments in ocean engineering. It is given annually by the Rosenstiel School of Marine and Atmospheric Sciences at the University of Miami to honor a scientist in the formative years of their careers. In order to accommodate the various disciplines on which ocean science is based, the award is presented on a rotating basis for achievements in six broad disciplinary areas: meteorology and physical oceanography; marine geology and geophysics, marine and atmospheric chemistry; marine biology and ecology; applied marine physics and marine affairs and policy. This year the award will be made in the general area of Marine Biology and Ecology. The general areas of interest include physiology, genetics, genomics, proteomics, ecology, behavior, population dynamics, connectivity, toxicology and conservation science in a marine field. Further information on the award can be found at our website <http://www.rsmas.miami.edu/about-rsmas/rosenstiel-award/>. Please forward your nominations by October 1, 2015 to Chris Langdon clangdon@rsmas.miami.edu University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149.

Located in Raleigh, North Carolina, NC State is the largest university in North Carolina, with more than 34,000 students and 8,000 faculty and staff. National rankings consistently rate Raleigh and its surrounding region among the five best places in the country to live and work, with a highly educated workforce, moderate weather, reasonable cost of living, and a welcoming environment. A collaborative, supportive environment for business and innovation and research collaborations with area universities and the Research Triangle Park are compelling reasons for relocation to the area. NC State is an equal opportunity and affirmative action employer. All qualified applicants will receive consideration for employment without regard to race, color, national origin, religion, sex, sexual orientation, age, veteran status, or disability. Applications from women, minorities, and persons with disabilities are encouraged.

Postdoctoral Research Associate in Oceanic Variability, Predictability and Change

The Atmospheric and Oceanic Sciences Program at Princeton University, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a postdoctoral research associate or a more senior for research related to intraseasonal-to-decadal oceanic variability, predictability and change. A key focus will be systematic comparison of observations and dynamical models to understand the character of and causes behind past changes to the ocean, with focus on the impact of the ocean on intraseasonal-to-decadal predictability. This would likely include assessment of and modifications to coupled and ocean data-assimilation systems. This will include assessments of predictability arising both from natural variability and radiative forcing changes. The research will also examine interactions between natural

decadal variability and the climate system response to radiative forcing changes, including attribution of observed ocean changes. The research will make extensive use of both observations and a variety of modeling tools, including newly developed high-resolution global climate models. The selected candidate will have one or more of the following attributes: (a) a strong background in physical oceanography, climate dynamics, or a closely related field; (b) experience using and analyzing advanced climate models and ocean observational datasets, and (c) strong diagnostic skills in analyzing large data sets.

Candidate must have a PhD. Initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding.

Complete applications, including a CV, publication list, at least 3 letters of recommendation, and a statement of research interests should be submitted by October 15, 2015 for full consideration. Applicants should apply online to <http://jobs.princeton.edu>, Requisition #1500567. For additional information, contact Gabriel Vecchi (gabriel.a.vecchi@noaa.gov).

This position is subject to the University's background check policy. Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Solid Earth Geophysics

Faculty Position in Geophysics at the University of Arizona

The Department of Geosciences at the University of Arizona seeks applications for a tenure track faculty position

in geophysics in the broad areas of geodynamics, seismology and/or geodesy. Candidates must hold a PhD degree by the time of appointment. Postdoctoral or other postgraduate research experience is desirable. We anticipate hiring at the tenure-track assistant professor level. The appointee is expected to develop and maintain a vigorous, collaborative, externally funded research program and to teach at the undergraduate and graduate level. Screening of applications will begin Sept. 10, 2015 and the search will continue until the position is filled. To apply, please submit: a cover letter, including references, curriculum vita, and statements of research and teaching experience and interests at this website: <https://uacareers.com/postings/3687>

Interdisciplinary/Other

ASSISTANT PROFESSOR OF EARTH AND ATMOSPHERIC SCIENCES (Exploration Geophysics)

Applications are invited for a tenure track position as Assistant Professor in the Department of Earth and Atmospheric Sciences at the University of Nebraska-Lincoln. The successful candidate will be expected to participate in teaching and curricular development of undergraduate and graduate courses, to advise and direct graduate students, and to develop a rigorous research program that is supported by external funding. It is expected that the research program will include field and subsurface-based studies of exploration geophysics. Ability to contribute to growing petroleum geoscience-related teaching and research activities within the Department of Earth & Atmospheric Sciences will be considered as an advantage. The candidate should demonstrate strong potential for research and teaching and must hold a Ph.D. in Geology, Geophysics, or a

related field at the time of appointment.

The Department of Earth and Atmospheric Sciences offers B.S. degrees in Geology and Meteorology-Climatology, as well as M.S. and Ph.D. degrees in Earth and Atmospheric Sciences. Primary research areas within the geological sciences include sedimentary geology, paleontology and paleobiology, petroleum geosciences and geobiology. Research in atmospheric sciences is focused on meteorological hazards, climate change, and remote sensing. Additional active research areas include Climate System Science, Geoscience Education and Hydrological sciences. Additional information about our department can be found on our web site: <http://eas.unl.edu>.

To apply, go to <http://employment.unl.edu>, search for requisition #F_150159 and complete the "faculty/administrative form". Applicants must attach a cover letter, curriculum vitae, statements of research and teaching interests, and names of at least three references via the above website. We will begin to review applications on October 12, but the position will remain open until it is filled.

The University of Nebraska is committed to a pluralistic campus community through affirmative action, equal opportunity, work-life balance, and dual careers.

For further information, contact Dr. Chris Fielding, Search Committee Chair by email, phone, or mail at: cfielding2@unl.edu, 1-402-472-9801; Department of Earth & Atmospheric Sciences, University of Nebraska-Lincoln, 214 Bessey Hall, Lincoln NE 68588-0340.

Physical Science Administrator (Program Director) Directorate for Geosciences National Science Foundation (NSF) Arlington, VA 22230

The NSF is seeking candidate(s) for a Program Director within the Education

Ten Faculty Positions Available at HAST

The Hadal Science and Technology Research Center (HAST) of Shanghai Ocean University in Shanghai, China invites applications for up to ten faculty positions at all ranks (Assistant, Associate, and Full Professor) in the following areas: Geological Oceanography, Chemical Oceanography, Physical Oceanography, Marine Biology and Microbiology. We are in the final stage of developing three full ocean depth (FOD) landers, one FOD hybrid AUV/ROV unmanned vehicle (ARV), one FOD human occupied vehicle (HOV), and a dedicated mothership of 4,800 ton displacement. We seek researchers, domestic and international, with strong experimental, instrumentation, or observational interests related to ocean science in general and hadal science in particular.

The positions are full-time and multi-year. A Ph.D. degree is required. The chosen candidate will be offered a highly competitive salary and start-up package, and will have full access to the state-of-the-art instrumentation and our FOD vehicles. Applicants should submit a cover letter, curriculum vitae with a publication list, a statement of research interests, and the names and contact information of three references. Send electronic materials to Ms. Song (tsong@shou.edu.cn) with Assistant (or Associate, Full) Professor Position in the subject line. Review and evaluation of applications will begin immediately. Applications will continue to be accepted until all available positions are filled. Information about HAST and its research activities may be viewed at <http://hadal.shou.edu.cn/>

and Diversity Program, Directorate for Geosciences (GEO), Arlington VA. The Directorate for Geosciences (GEO) recognizes that active support of geoscience education and workforce development must be a significant element of GEO's mission to promote the overall health of the enterprise. This commitment extends beyond GEO's traditional support for graduate student training and includes support for activities that advance geoscience education reform at the undergraduate and pre-college levels and improve public understanding of the geosciences and its contributions. Included in these activities are focused efforts to broaden participation of underrepresented groups in the geosciences.

More information about GEO and its programs can be found at <http://www.nsf.gov/dir/index.jsp?org=GEO>.

The Directorate for Geosciences (GEO) supports activities designed to improve the education and human resource base in research areas that advance the state of knowledge about Earth and the processes that modify them. The Program Director for Education and Diversity coordinates and leads Directorate-wide activities focused on increasing representation within the geosciences community and expanding and enriching geosciences education at all levels. The Program Director chairs the GEO Education Team and participates with the GEO leadership team in developing education and diversity strategies and recommending assessment and budgets for GEO education programs. He/she evaluates proposals and prepares recommendations for awards and nominations. The Program Director acts as liaison to internal NSF groups and programs with similar interests and accurately reflects NSF policy and procedures to the public, the scientific community, and external organizations, including other Federal agencies. He/she also interacts with the university community and is aware of the challenges and opportunities that are important considerations for developing a GEO education strategy.

Candidates must have a Ph.D. in a Geosciences field plus, after award of the Ph.D., six or more years of successful research, research administration, and/or managerial experience pertinent to the position. Experience pertinent to the position includes activities that demonstrate proficiency in a disciplinary area of the geosciences plus geoscience education theory, practice, assessment, research on learning and/or leading substantial education or outreach projects; and being recognized in the community as a leader in this area.

Individuals interested in applying for this vacancy should submit their materials to announcement GEO-2015-0001 - Permanent & GEO-2015-0002 - Rotator. The position requirements and application procedures are located on the NSF Home Page at www.nsf.gov.

[gov/about/career_opps/](http://www.nsf.gov/about/career_opps/). Hearing impaired individuals may call TDD 703-292-5090. If you have questions about the application process contact Dominique McCracken at 703-292-2415 or email: dmcrcrack@associates.nsf.gov. Applications must be received by September 25, 2015.

NSF is an equal opportunity employer committed to employing a highly qualified staff reflecting the diversity of our nation.

POSTDOCTORAL POSITION IN PLANETARY SCIENCE PURDUE UNIVERSITY

Purdue University's program in planetary science has an opening for a PhD researcher to model the evolution of crater-generated porosity in the lunar crust using a crater terrain evolution model in conjunction with constraints from GRAIL gravity data. A PhD in physics, geophysics or planetary science and experience in modeling is required along with familiarity with computer languages such as FORTRAN or C in a LINUX environment. The position is available immediately and will run for approximately 1 year with the possibility of extension pending availability of funding. Please send a vita, bibliography and the names of three referees to Professor H. Jay Melosh, Earth and Atmospheric Sciences Department, 550 Stadium Mall Drive, West Lafayette, IN 47907, or to jmelosh@purdue.edu by October 31, 2015. A background check is required for employment in this position.

Purdue University is an EEO/AA employer fully committed to achieving a diverse workforce. All individuals, including minorities, women, individuals with disabilities, and protected veterans are encouraged to apply.

Two Full-Time Permanent Research Positions in the National Research Program, U.S. Geological Survey, Reston, Virginia.

Flow and Transport in Fine-Grained Geologic Media (Position 1)

The National Research Program (NRP) (<http://water.usgs.gov/nrp/>) of the U.S. Geological Survey seeks candidates for a full-time permanent research position in subsurface flow and transport at the GS-11, GS-12, or GS-13 grade, in any of the following series: Research Hydrologist, Research Geologist, Research Petroleum Engineer, and/or Research Physicist. Salary Range: (\$63,722 to \$118,069). This is a position for an early-career scientist to conduct research on fluids in fine-grained, low-permeability formations, including shales, mudrocks and clays. USGS seeks to better understand fluid flow and transport in these environments when subjected to natural and human-induced changes on engineering to geologic time scales. An important aspect of the position will be to develop analysis capabilities in multiphase fluid transport and / or poromechanical coupling. The successful candidate

will focus on behavior at formation and larger scales, and will integrate theoretical and numerical analysis with field and laboratory data.

A completed or pending Ph.D. in a relevant subject area is desired, as is competence in numerical simulation methods. Experience with field and laboratory investigative techniques is also desirable. Good communication skills are essential.

Sediment Radionuclide Geochemistry (Position 2)

The U.S. Geological Survey seeks candidates for a full-time permanent research position in sediment radionuclide geochemistry at the GS-11, GS-12 or GS-13 grades. This early-career interdisciplinary position in the National Research Program (<http://water.usgs.gov/nrp/>) may be filled under these job series: Research Chemist or Research Geologist or Research Hydrologist. Grade and salary (\$63,000 to approximately \$100,000) will be based on education and experience. Prior to starting employment with the USGS, a successful applicant will have demonstrated educational and research accomplishments, through the obtainment of a Ph.D (or equivalent education and experience) in a field related to radionuclide geochemistry. Experience will include

analyses of radioisotopes in environmental samples (naturally-occurring or nuclear fuel cycle generated radionuclides) as well as research in areas such as heavy/trace metal geochemistry, mineralogy, and soil or sediment science. The applicant will have demonstrated scientific vision, leadership, and productivity in exciting, societally-relevant, and collaborative inter-disciplinary research topics.

The successful candidate will lead development of laboratory capabilities and research applications in the area of radionuclide geochemistry. The scientist will collaborate with hydrologists, geologists, chemists, ecologists and microbiologists in the USGS and provide assistance and direction in methods development for the Center for Sediment Dynamics and Forensics (CSDF), a developing center of excellence. The CSDF is expected to apply a full range of observational and experimental techniques in both the laboratory and the field. Examples of techniques to be employed by the CSDF include: radiometric techniques (^{14}C , ^{137}Cs , ^7Be , ^{210}Pb , ^{234}U / ^{238}U , and other radioisotopes), optically stimulated luminescence, electron spin resonance, X-ray diffraction mineralogy, stable isotopes of light and heavy elements, major-element analysis, geo-

EMPLOYMENT ANNOUNCEMENT

Researcher Position in Climate and Atmospheric Chemistry

Research Center for Environmental Changes

Academia Sinica

TAIPEI, TAIWAN

The Research Center for Environmental Changes invites applications at the Assistant, Associate and Full Research Fellow levels in the following fields:

- 1) Diagnostics and modeling of climate variability and change, and climate model development;
- 2) Atmospheric chemistry, particularly relevant to the changes in regional atmospheric composition and air quality.

One position for each field beginning in 2016 is available. Applicants are expected to have a doctoral degree in related fields by start of the appointment. Further information about the Research Center for Environmental Changes and related research can be found at <http://www.rcec.sinica.edu.tw/>.

Applicants should send their curriculum vitae, research plan and the names of three referees, before October 15, 2015, to:

Dr. Huang-Hsiung Hsu, Chair
Researcher Search Committee
Research Center for Environmental Changes,
Academia Sinica,
128, Academia Road, Section 2
Taipei 115, Taiwan
Tel: +886-2-2652-5173
Fax: +886-2-2783-3584
E-mail: hhsu@gate.sinica.edu.tw

, and also a copy to Dr. Charles C.-K. Chou (ckchou@gate.sinica.edu.tw).

Both regular and electronic mails are acceptable. Upon receipt of the application, an acknowledgement email will be sent to the applicant within a week. Applicants who do not receive the acknowledgement email please contact the Chair of the Researcher Search Committee via email or telephone for confirmation.

chemical phase analyses, organic molecular markers, rare earth and trace element distributions, and carbon and nutrient analyses.

To Apply:

The positions will be located in Reston, Virginia in the Eastern Branch of the National Research Program (NRP). The NRP is a program in the USGS Water Mission Area and offers a stimulating and collegial environment for research in water-related earth science to meet current and anticipated national needs. NRP researchers collaborate with scientists nationally and internationally as well as with other USGS scientists nationwide.

The on-line vacancy announcements, which will be posted at the Office of Personnel Management's USAJOBS website (www.usajobs.gov) contains additional information regarding qualification requirements. The vacancies will be open for 30 days starting on or about September 1, 2015. Applications (resumes and questionnaire responses) must be received online BEFORE midnight Eastern Time on the closing date posted in the USAJOBS Vacancy Announcement. It is important that candidates view the Vacancy Announcement in their entirety to be sure that all required documents are submitted. Incomplete application packages cannot be considered. For further information, please contact: Greg Desmond (703-648-4728, gdesmond@usgs.gov, Position 1

and 2) or Pierre Glynn (703-648-5823, pglynn@usgs.gov, Position 1 and 2), or Katherine Skalak (703-648-5435, kskalak@usgs.gov, Position 2) in the Eastern Branch of the NRP.

US Citizenship is required for this position. For any US Citizen (including current or former Federal employees), the Vacancy Announcement number for Position 1 is: ATL-2015-1005. For any US Citizen (including current or former Federal employees), the Vacancy Announcement number for Position 2 is: ATL-2015-1182. The USGS is an Equal Opportunity Employer.

Visiting Assistant Professor: Geospatial Analytics, Climate Change Adaptation, and Coastal Processes. The College of Earth, Ocean, and Atmospheric Sciences at Oregon State University located in Corvallis, Oregon invites applications for a 9-month (1.0 FTE) or 12-month (0.75 FTE) visiting position as Assistant Professor. The position is anticipated to begin in January 2016 and end June 2017. We are seeking a colleague that will unite expertise in geospatial analysis, physical aspects of climate systems, and a specialization in social science approaches to adaptation, vulnerability, and planning for climate change and coastal processes. This candidate will conduct research, teaching, and outreach to improve data, methods, and scenarios of vulnerability and resilience, and identify thresholds of

human and natural systems to climate change. Responsibilities: Establish a program of research and teach undergraduate and graduate courses in concepts and methods of adaptation, vulnerability, and planning for climate change and coastal processes, and in geospatial analytics; and service. Requires: PhD, by the start of employment, in geography or other fields that supports geospatial analytics and planning; scholarly potential demonstrated by a record of peer-reviewed publications and a clearly defined research agenda; strong potential for teaching excellence and mentoring undergraduate and graduate students, and post-docs. See announcement at: <http://ceos.oregonstate.edu/employment/>. To apply go to <https://jobs.oregonstate.edu/posting/0015663>. For full consideration, apply by 10/01/2015. Closing date: 11/01/2015

Student Opportunities

Graduate Student Fellowship in the Collaborative PhD Program of the American Museum of Natural History

The AMNH Dept. of Earth & Planetary Sciences seeks students for collaborative AMNH-Columbia U. and CUNY PhD programs. Areas of research include petrology/high-temperature geochemistry, volcanology, mineral deposits, and meteoritics/planetary sciences. Students must apply simultaneously to Columbia or CUNY and

AMNH and are expected to conduct research under the direction of a museum scientist. Students in good standing receive a full 12-month stipend and tuition for 4 years. Applicants should discuss their interests and background with a potential advisor. For details see <http://bit.ly/EPStuOp>. Application deadline is 12/15/15. For questions contact Dr. George Harlow, gharlow@amnh.org.

PLACE YOUR AD HERE

Contact
advertising@agu.org
for information

AGU Career Center Tools to Help You Manage Your Career

With the AGU Career Center you can:

- Participate in Career Advice Workshops and Webinars
- Regularly update your resume to manage and track your career accomplishments
- Access information from past Career Advice Workshops and Webinars
- Search and respond to job listings
- Access resources to help manage your current and future career



careers.agu.org



Postcards from the Field

Bryan Curtis and Ori Chaffe measuring carbon dioxide (CO_2) and methane (CH_4) flux from degrading permafrost at field sites on the Seward Peninsula.

Having made similar measurements for three years at the Barrow Environmental Observatory (BEO) on the North Slope of Alaska, we thoroughly enjoyed the diversity of vegetation and variable terrain of the landscapes to the east of Nome, near Council, Alaska.

The mosquitos, however, are just as numerous and obnoxious. Check out our Next-Generation Ecosystem Experiments Arctic website for more information (<http://ngee.ornl.gov/>).

—Stan Wullschleger, Ph.D.
Oak Ridge National Laboratory

View more postcards at
<http://americangeophysicalunion.tumblr.com/tagged/postcards-from-the-field>.

2016
OCEAN
SCIENCES
MEETING

21–26 February • New Orleans, Louisiana, USA



Submit an Abstract for Presentation



Abstract Submission Deadline:
23 September 2015

The theme for the 2016 Ocean Sciences Meeting is **Ocean Sciences at the Interface**. Complex interactions often occur at interfaces. Interactions at these interfaces occur on a wide range of spatial and temporal scales, and these interactions are critical for understanding the world around us and implementing informed policies in a global society. The meeting will highlight processes at interfaces and how the work at such interfaces pervades the study of ocean sciences and shapes the impact of our research on society.

osm.agu.org